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THE INFLUENCE OF SEDIMENT FROM LANDSLIDE PLUMES ON SESSILE KELP FOREST ASSEMBLAGES

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ABSTRACT

THE INFLUENCE OF SEDIMENT FROM LANDSLIDE PLUMES ON SESSILE KELP FOREST ASSEMBLAGES

by Kim Kiest

Earthquakes and winter storms cause episodic landslides which dump large quantities of sediment into kelp forest communities along the northern and central coast of California. The major ecological impacts are from direct burial of sessile communities, sand scour, and deposition of suspended fine sediment in plumes. This study focused on the latter. Sediment plumes persist until waves erode fine material and the slide becomes armored with large boulders. Data from $0.25m^2$ photo quadrats showed that boulder surfaces under landslide plumes were covered by 40% more sediment compared to kelp forest communities without plumes. Many sessile organisms decreased in cover under plumes. Geniculate coralline algae decreased by 30% and sessile invertebrates decreased by as much as 15%. Total biomass decreased by 25% in plume influenced areas. A few species, like the cup coral Balanophyllia elegans, barnacles and some fleshy red algae, appeared more tolerant to sedimentation or responded positively to the absence of less tolerant species. Reduced abundances of sessile organisms in areas influenced by plumes may result from low recruitment.

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INTRODUCTION

The sea floor is largely covered with mud and sand. Only a very small portion harbors rocky substrates and other reefs: these mostly fringe the shallow coastline. Although soft bottoms are the ultimate sink for most sediment many reefs are influenced by sedimentation through direct burial, scour and gradual deposition. The disturbance caused by the input of sediment to the marine environment can alter trophic structure and influence community relations.

Impacts of sedimentation on hard bottoms are best known from coral reefs, where human modifications of watersheds cause severe soil erosion and input into tropical waters (Hodgson and Dixon 1988, Johannes 1976). The evidence for these impacts is usually anecdotal, involving observations only after sediment inputs apparently increased (Roy and Smith 1971) and rarely with convincing comparisons to communities without sedimentation (Rogers 1990). Even the best of these studies do not include correlative data on the actual quantity of sediment in the water around the reef (except see Loya 1976) or any field manipulations (Grigg 1975, exception; see Sakai et al. 1989). Comparatively little work has been done on temperate rocky reefs and, because of the great differences between temperate and tropical settings, few generalizations can be made from tropical reefs that are relevant to temperate shores.

Sedimentation processes in rocky intertidal communities in temperate zones have generally received more attention than subtidal communities because they are more accessible and easier to manipulate. The effects of direct burial by sand has been the major interest in the intertidal (Markham and Newroth 1972, Markham 1973, Littler et al. 1983, Littler and Littler 1984, Robles 1982, Taylor and Littler 1982). Little experimentation has been done on sedimentation effects on subtidal rocky reefs (except see Weaver 1977).

There are anecdotal observations of sedimentation effects on subtidal assemblages (Foster and Schiel 1985); however, descriptive evidence is often nonquantitative and Gotelli (1988) is one of few to do field experiments.

The subtidal rocky reefs of California are the foundation for impressive giant kelp forests. These kelp forests grow to their deepest possible limits in the Julia Pfeiffer Burns Under Water Park of Big Sur. In 1974 this area was designated as an Area of Special Biological Significance by the California State Water Resources Control Board (Seltenrich et al. 1980). Several factors combine to enhance giant kelp forest survivorship in the Big Sur area: hard substrates for kelp holdfast attachment, cool temperatures, and high nutrients.

Kelp, other algae and sessile invertebrates are probably the most suseptible to sedimentation since motile species are capable of leaving the disturbed area (Menge and Farrell 1989, Menge and Sutherland 1987). Suspended sediments may reduce the amount of light available to the plants. Scour may damage or remove plants or invertebrates. Sediment deposition may limit space available for recruitment, act as an unstable substrate on which to settle, or smother established organisms.

There are two major sources of sediment input to kelp forest assemblages along the Big Sur Coast: Rivers and coastal landslides. Rivers are the most common; the sediment plumes they create are large and highly seasonal in occurrence. Associated freshwater may be a difficult variable to separate when considering sedimentation influences, especially in shallow water. Earthquakes and heavy rains cause episodic landslides that dump large quantities of sediment into marine assemblages along the California coast. Although erosion of the shoreline is a widespread process, it is locally intensified along parts of the Big Sur coast where the unstable sedimentary rock and steep coastal cliffs are prone to frequent and sometimes massive landslides. Sediment plumes from landslides are smaller and more persistent than river plumes, influencing relatively distinct local areas. Freshwater inputs are minor from landslides. There are very few studies on coastal landslides. Only Stephens (1990) has considered the impacts on subtidal flora and fauna, but no comparisons were made to areas without sediment. Past scientific studies focused on either the rocky habitat or the soft bottom area, rarely considering the extensive interface between the two. As a result, although sedimentation is common in coastal environments, there is little understanding of how this process disturbs and structures natural assemblages. Sediment plumes in the water column below coastal landslides may persist for years until the slide is stabilized. The McWay Landslide in Big Sur produced a large plume. Plume impacts may be detected in the adjacent kelp forests at McWay rocks. This study focused on the ecological impacts of sediment deposition from landslide plumes on kelp forest assemblages. Unfortunately, no data were available on the structure of the kelp forest prior to the slide, but nearby kelp forests unaffected by the plume were used for comparison. The general hypothesis was that sedimentation from landslide plumes did not impact the structure of kelp forest assemblages. The following hypotheses were tested:

1. The percent cover, biomass and diversity of invertebrates and algae in kelp forests influenced by landslide plumes are no different from those that are not.

2. Invertebrates and algae transplanted into kelp forests influenced by landslide plumes and those that were not will show no difference in survivorship.

3. There is no correlation between water column turbidity and patterns of invertebrate and algal assemblages below sediment plumes.

METHODS

Site Description

Although landslides are frequent on the Big Sur coast, highway maintenance like that which took place after the big slide at McWay Rocks in Big Sur caused unknown additional impacts to marine communities by putting more sediment into the nearshore marine environment than the original event (Photo 1). The slide at McWay Rocks occurred after heavy rains in the winter of 1982-1983. This slide (approximately 0.5 km wide) closed Highway 1 for an entire year. The slide was cleared from the highway by moving over 3 million m^3 of soil from the upper face (above the highway) of the slide and placing it at the toe (Photo 2). This added approximately 75 m of sediment to the base of the cliff burying a large area of the intertidal habitat as well as subtidal marine environment and forming a new beach. Since 1983 approximately 916, 000 m^3 of sediment has eroded from the lower slide face due to rain, run-off and surf action. Unfortunately, none of the slide sediment was stabilized with vegetation, and there was no attempt to armor the base with large boulders. The drainage system from the upper slide flows directly onto the lower slide face and has eroded approximately 257,000 m^3 in one area forming a large unstable canyon (Photo 3). Erosion of the slide has been much less severe than is possible because, until 1992-93, rainfall was well below average since the slide occurred. Despite this, a large sediment plume persists in the water column below the slide (photo 4).

Two experimental sites were chosen which were within the sediment plume created by the McWay Slide (fig 1). These were a small kelp forest (Little McWay) separated by a sand channel approximately 30m wide from a larger kelp forest (Big McWay). Another kelp forest site within a plume was located below the Torre Canyon Slide (fig 1). Three sites were selected for comparison with the plume impacted sites (fig1). These were all kelp forests outside of plume impact areas (initially based on visual comparison; however, see suspended material results p.17) located between the Torre Canyon Slide and McWay Slide areas (Partington Launch, Partington South and McWay North). All stations were on the edge of the kelp forests (since kelp may limit spread of plume), on the horizontal surfaces of large boulders.

Percent Cover/Biomass/Diversity

Photo Quadrats

To document differences between kelp assemblages influenced by sediment plumes and those that were not, 6 replicate $0.25m^2$ photos were taken once a year, in the fall from 1987-1991 at each site. To sample, a diver was given a compass reading that would lead him/her along the kelp edge. A random number of kicks was used between each placement of the quadrat. The diver maintained an average depth of 13m. If the diver did not land on a boulder surface he/she would kick again to a new area. A Nikonos V with strobe was used for all photographs. Slide photos were then analysed for percent cover of particular species by projecting the image onto a grid of 100 equally spaced points. Species below each point were identified to the lowest possible taxon and counted as 1%. Where patterns were noted graphically these were analyzed using the Mann-Whitney U test to determine significant differences between plume influenced sites and sites not influenced by plumes. The mean for each of the 6 sites was calculated. The means for each year at the 3 plume influenced sites (n=5) were compared to the means for each year at the 3 sites not influenced by plume sediments (n=5). Percentages were arcsine transformed for all statistical analyses presented.

In 1987 $0.25m^2$ photos were taken in the center of the Big McWay kelp forest (Big McWay B, fig 1) as well. This site is further north than the Big McWay site described above and is less affected by plume sediments. These photos were considered along with those from the regular Big McWay Site (called big McWay A for these analyses) and McWay North for that same year to show differences in algal cover along a gradient away from the plume. Where patterns were noted graphically, significant differences in algal and sediment cover along this gradient were determined using a one factor analysis of variance (ANOVA) with the Scheffé F multiple comparison test (n=6).

To get a better view of understory invertebrates and algae, photos using a close-up lens were also taken in the fall of 1990 at the 6 sites. The area photographed was 24 x 17 cm. This method of determining percent cover was compared to the $0.25m^2$ quadrat method to determine which was optimal for this type of sampling.

Point Quadrat/Stipe Counts

Percent cover of the subtidal understory algae was also examined along a gradient away from the plume at the McWay landslide in October 1991 using point quadrats. This method was used to allow a comparison between point and photo quadrats since it may be difficult to assess cover in 3-d assemblages when relying on photos (Foster et al. 1991). To do this 2 more sites were added in the Big McWay kelp forest (Now Big McWay A, the densest part of the plume), one at the center (Big McWay B, less plume influence) and one farther north (Big McWay C). McWay North (little or no sediment influence) was also compared to these (fig.1). Depth was kept near 13 m. At a random number of kicks off of a transect line, a one meter long point quadrat (similar to that described by Cowen et al. 1982) was placed on the substrate. The bar had a 1.5m long string with five knots on it which was attached to both ends of the bar. When a knot on the line was stretched tightly away from the bar, it was placed on the substrate and whatever it contacted was identified and recorded (only algal species were considered here). All knots on both sides of the bar were recorded totaling ten points although the final count may have been more than ten organisms if one knot came into contact with more than one organism (i.e., a fleshy red algal branch with a kelp holdfast underneath it). There were six replicates examined off the transect line at each site. Where patterns were noted graphically, differences in algal cover along this gradient were analysed using a one factor analysis of variance (ANOVA) with the Scheffé F multiple comparison test (n=6).

Kelp stipes were counted when present in the area being sampled for understory. A $4m^2$ 3-sided quadrat was placed on the substrate next to the point quadrat. This type of quadrat was used because in areas with kelp the "missing" side allows the quadrat to be placed over the attached kelp. All brown stipes, 0.5 m off the bottom, within the quadrat were identified and counted.

The point quadrat method was used at each of the 6 regular sampling sites as well. This method was compared to the $0.25m^2$ photo quadrat method of data collection using the 1991 data only to determine if one method was optimal. Other comparisons were made of data collection methods and sampling times. One of these was taking a $0.25m^2$ quadrat and photographing the area on which it was placed as found naturally and then taking another photo of that same area after the larger and possibly obstructive laminarians had been clipped away. Another comparison was made to determine if sampling time was biasing the results. Photos were taken using the $.025m^2$ quadrat in February 1988 (all other sampling was done in the fall of each year). These photos were compared to those taken in September 1987 and October 1988.

Destructive (Scrape) Samples

Three destructive samples were taken from each site to note differences in biomass and diversity in plume and no plume areas in October 1990. A 0.125 m^2 quadrat was placed at random (random compass reading and 10 kicks) intervals on boulder surfaces.

All organisms within the quadrat were scraped off using a regular stainless steel paint scraper and placed in a labelled ziploc bag. Contents were later preserved with 10% formalin. Contents were weighed (g) and separated into phyla. Individual species were identified when possible (Appendix A). Differences in total biomass and the biomass for particular algal and animal groups at the plume and nonplume sites were analyzed using a two-tailed paired sample t-test. The means of the 3 destructive samples were calculated for each site and then the 3 means for the plume influenced sites (n=3) were compared to the 3 means for the sites not influenced by a plume (n=3). Diversity differences were measured using this same test. Here diversity was defined as the total number of taxa present.

Transplants

The percent cover of organisms determined from 0.25m^2 photos of previous years was used to determine the best canditates for transplantation. For example, if a plant or animal had an average percent cover that was much different between sites influenced by plume impacts and those that were not, this organism was selected for transplantation. Organisms were only transplanted if they were robust enough to survive the process. Transplanted items were sponges, tunicates, geniculate coralline algae, fleshy red algal species and cup corals.

PVC Plates

A rack was made to place over the existing sediment tube structure (see following description and Appendix B fig. 1) to support tranplanted organisms. This rack was a rectangle (30 x 60 cm) made of 2 cm PVC pipe and elbows. One 25 cm^2 PVC plate was bolted to each corner (Appendix B fig 2a). A commercially used underwater epoxy (no label) was mixed and placed in an empty cartridge in a calking gun to glue invertebrates and algae to the PVC plates. A pilot study in 1989 demonstrated the adhesion properties of this epoxy in situ and in aquaria, with no adverse effect on the organisms. One sponge (either Acarnus erithicus or Polymastia pachymastia), 1 tunicate (either Aplidium solidum or Polyclinum planum), 2 Balanophyllia elegans, 1 Rhodymenia sp., and 1 Calliarthron sp. were glued to each plate at the surface (Appendix B fig 2b). When these seemed secure the whole structure was brought down to the existing sediment rack at the site and secured with cable ties. These were placed at the 6 sites in October 1990.

Sponge Plates

To determine if sponges were affected by the McWay plume, 12 Tethya aurantia were transplanted into both McWay North (no plume) and Big McWay (plume present) in July, 1991 (these 2 sites were assumed to be different based on photographic and suspended material samples). T.aurantia were used because they are easy to manipulate and are known to be negatively affected by sediment (Rosenthal 1974). Six 30 cm circular cinder plates were used as stabilizing bases to bolt down PVC plates (Appendix B fig 3a). Onto each 25 cm^2 PVC plate were attached 4 plates made of thick flexible plastic (10 x 10 cm), each supporting 1 T.aurantia (Appendix B fig 3b). The T.aurantia were pierced in the center with cable ties and then cable tied to the plastic through holes. These were then cable tied to the PVC plates. Three plates were placed at McWay North (no plume) and 3 at Big McWay (plume present). These were monitored 3 and 10 months later.

Balanophyllia elegans Plates

To determine if sedimentation affects Balanophllia elegans 60 of these cup corals were transplanted into McWay North (no plume) and 60 into Big McWay (plume present) in July, 1991. Corals in other habitats are known for their sediment rejection capabilities, such as trapping sediment in mucus and moving it off coral surface via cilia (Johannes 1976, Rogers 1990). Six 30 cm circular cinder plates were used as stabilizing bases to bolt down two 10 x 20 cm plexiglass plates (Appendix B fig 4a). Threaded through these plates was 0.6 cm surgical tubing to be used to hold down two 5 x 20 cm PVC plates with 11 Balanophyllia each epoxied to the surface (one extra was added in case of loss in transport etc., Appendix B fig 4b). Three plates were placed at McWay North and 3 at Big McWay. These were monitored 3 and 10 months later.

Kelp Bags

To determine if sedimentation affects recruitment and growth of young Macrocystis pyrifera, M. Pyrifera sporophylls with reproductive sori on them were collected to 1/2 fill eight yellow mesh bags (15 L approx., Appendix B fig 5). Inoculating sites by concentrating fertile sporophylls should result in higher recruitment of algae to an area (Schiel and Foster 1986). Mesh bags were used to keep sporophylls in place and hopefully limit predation (North 1964). These were transferred to the McWay North and Big McWay sites via covered cooler in July1991. The kelp bags were anchored in four circular 2 m^2 cleared areas at both McWay North and Big McWay in hopes that spores would be released in a concentrated area so cover of the young plants could be determined at each site. After 3 and 10 months in the field (enough time for juveniles to be visible if present, Anderson and North 1966), a 2 m^2 circular quadrat was used to count all young Laminarians that the line intercepted since juveniles from adult plants should be most abundant in this range (Anderson and North 1966). The pivot point for the circular quadrat was the site where mesh bags filled with sporophylls had originally been placed.

Geniculate Coralline Algae Plates

To determine if geniculate coralline algae growth is affected by sediment plumes, 6 recruitment plates were placed within dense geniculate coralline algae beds at Partington Launch in April 1991 to coax recruitment. These plates consisted of 30 cm circular cinder plates with 30 cm^2 plexiglass squares bolted to them. After a bumpy coralline crust covered nearly 50% of each plate (maximum 65% cover) 6 months later (assuming this to be geniculate coralline crust, Johannsen 1966), 3 plates were transferred to Big McWay (13 m) and 3 were moved to a new location at Partington Launch (12 m) away from geniculate corallines. Percent cover of geniculate corallines on each plate was determined in April 1992. Differences in cover at plume and nonplume sites were determined using the two-tailed paired-sample t-test (n=3).

Boulders

Moveable boulders (max 9 kg) with attached sessile invertebrates and algae were transplanted into each of the 6 sites as well. Three boulders were placed at each site in October 1990. Pink flagging tape was tied around each boulder with the knot marking the top surface. Percent cover of invertebrates and algae were determined for each boulder at the beginning and end (Oct. 1991) of the sampling period.

Sedimentation/Plankton

Sediment Tubes

Sediment tubes were deployed within the 3 plume and 3 areas without plumes in October 1990 to estimate rates of sedimentation. Sediment tubes were made of 5 cmPVC pipe cut into 38 cm lengths following specifications for optimum particle capture (Bhosle et al. 1989, Butman 1986, 1989). One end of each section was capped with a 5 cm PVC pipe cap. Six racks were constructed from 0.6 cm rebar to support 3 tubes at each site. Thirty centimeters separated each tube on a rack to prevent any negative influences between tubes. The tubes were cable tied to the rack so their mouths were 1 meter off the bottom. The base of the rack was weighted with cement which was buried in the substrate and covered with large boulders to stabilize the structure. Lines tied to fence anchors buried in the sand were also used for stabilization (Appendix B fig 1). Tubes were checked 8 days and 6 months later.

Plankton Tows

To determine whether sessile invertebrates were available for recruitment in sediment plumes, three 5min. plankton tows were made in both the McWay and Torre Canyon Slide plumes in October 1990 using a standard zooplankton net. The net was 2m long and had a 0.5m diameter mouth opening. The boat was kept at the lowest speed possible which would keep the net in a horizontal position near the surface. Plankton was preserved in 8% formalin and later identified to the lowest possible taxon and its presence in the plume noted. Approximate counts (#/5min tow) were made for larvae of sessile invertebrates central to this study. In October 1992 three plankton tows were made in the McWay plume and further north away from the plume to note differences in plankton abundance. Methods were the same as above.

Armor vs. No Armor

Cliff side photographs were taken of several slide areas along the Big Sur coast in February 1991. The soft, metasedimentary rock cliffs in the Big Sur often fall prey to landslides creating sandy beaches where before there were none. As time passes the lighter sediments are winnowed away by surf action, leaving only the heavier boulders behind.

Prior to this, plumes occur in the nearshore marine environment. From the cliff side photos it was determined whether the slide was armored (i.e., having larger boulders to support its base), unarmored (i.e., having a sandy beach) or partially armored (Boulders and some sand or small pebbles). A qualitative measurement of the plume associated with each of these areas was also made (large, medium, small or no plume). The Chi-Square Test for Goodness of Fit was used to detemine if plume size was correlated to the amount of armoring at the base of a slide.

Suspended Sediment

Water column samples were taken in Sept 1991 and April 1992 to correlate actual suspended material data with the patterns noted in the sessile community. Niskin bottles were used to sample water both inside and outside the plume associated with the McWay Slide. Samples were taken 1 m below the surface and 1m off the bottom along a gradient away from the plume. Plastic 150 ml bottles were rinsed 3 times with the sample water and then filled and labelled for location. These samples were then returned to the lab and filtered through 1μ type EA glass fiber filters using a vacuum pump. Sample paper was weighed before drying. Filtered samples were then dried in an oven and weighed (mg/l). A model TR2005 Sea Tech Inc. 5cm pathlength transmissometer was also used to measure % transmittance and the volume of suspended material in the water column. Percent transmittance was converted to mg/l and compared to filtered water samples giving an acceptable correlation (R-squared = .997, $p < .01$) between the two methods.

Aerial Photos

Aerial photographs were taken on the same day when suspended material data was being collected at the McWay land slide. The total area of plume coverage was determined using computer scans of the these photos. An estimate of the volume of suspended material within the entire plume was determined using the suspended material data for that day and assigning these values to a particular gray scale of the scanned photograph. Aerial photos and direct slide measurements were also used to estimate slide size and amount of sediment moved (Horikawa and Sunamur 1967). These values were included in the site description (p. 4).

Aerial photos taken over the past 50 years were examined at the library of the University of California, Santa Cruz. The sites of the McWay Landslide and Torre Canyon Slide were studied for plume presence and persistance as well as other factors. Another large slide at Lucia was not examined subtidally but was included here for comparison.

RESULTS

Percent Cover/Biomass/Diversity

For 5 years the $0.25m^2$ photo quadrats showed that at the 3 sites below sediment plumes (Big McWay, Little McWay and Torre Canyon Slide) there was a greater cover of sediment and barnacles (figs 2 & 3) than at the 3 sites without sediment plumes (McWay North, Partington South and Partington Launch). However, only sediment cover showed a significant difference ($p < .05$). There was always a fine layer of sediment on horizontal surfaces during sampling periods. Geniculate coralline algae (fig 4), sessile invertebrates (sponges, colonial tunicates and bryozoans, fig 5) and brown algae (primarily laminarians, fig 6) were less abundant in plume areas but only geniculate corallines and sessile invertebrates showed significant differences ($p < .05$). There was no difference between sites for upright vs. encrusting Bryozoan cover. The close-up quadrat did not provide a more thorough assessment of the sessile invertebrates than the $0.25\ m^2$ quadrat except for bryozoan cover which did not differ, when using the close up lens, between plume and no plume sites anyway. The close-up quadrat often missed the larger laminarians and had larger variances (Appendix C figs 1 & 2).

Using the point quadrat, the percent cover of algae was determined along a gradient away from the McWay plume in 1991. The mean depth was 11 ± 0.12 m. Samples out of the plume had more geniculate coralline algae with significant differences occurring between each of the 3 Big McWay sites (A, B and C) and McWay North ($p < .05$, fig 7). Encrusting corallines, <u>Rhodymenia</u> sp. and other fleshy red algae were more abundant at sites within the plumes (fig 7). Encrusting coralline cover showed significant differences between each of the 3 Big McWay sites (A, B and C) and McWay North ($p < .05$). <u>Rhodymenia</u> sp. cover was only significantly different between Big McWay A (nearest to the densest part of plume) and McWay North (outside plume, $p < .05$). Red algal cover was significantly different between Big McWay A and McWay North ($p < .05$) and Big McWay B and McWay North ($p < .05$). Data from 1987 $0.25m^2$ photo quadrats were examined for changes along the gradient at McWay as well (fig 8). There was more sediment and encrusting coralline cover near the plume but only encrusting coralline cover showed significant differences between McWay North and Big McWay A ($p < .05$) and Big McWay A and Big McWay B ($p < .05$). Geniculate corallines and brown algae were more abundant away from the plume but only geniculate coralline cover showed significant differences which were between McWay North and Big McWay A ($p < .05$) and Big McWay A and Big McWay B ($p < .05$). Stipe counts of kelp did not show any particular trend.

The point quadrat method was compared to the $0.25m^2$ photo quadrat method of data collection (Appendix C, fig 3). The only difference was a greater percent cover of encrusting coralline algae in the plume areas using the point quadrat. The variances were less when using the point quadrat, but since this method takes a good deal more dive time, which is very limited when working along the Big Sur Coast, the $0.25m^2$ photo quadrat was still the method of choice. Two other comparisons of data collection methods and sampling times were considered (Appendix C). One of these was comparing a $0.25m^2$ photo quadrat taken of an area as it appeared initially to one at the same spot where the larger laminarians had been clipped away. There were only slight increases in percent cover of organisms in the clipped quadrats because of their being more clearly visible (Appendix C, fig 4). The variances were similar between the two methods. Again, since the differences were minimal and clipping takes a good deal of dive time, not clipping the laminarians was the method of choice. Another comparison was made to determine if sampling time was biasing the results by comparing photos from February 1988 to those taken in September 1987 and October 1988. No consistent differences were noted between sampling times; each period showed fluctuations (Appendix C, fig 5).

The total biomass (g) of invertebrates and algae from scrape samples was compared between plume and no plume areas. Total biomass was significantly different in areas not influenced by plume sediment ($p < .05$, fig 9). Biomass of particular invertebrate and algal groups was usually, although not significantly, higher in areas not influenced by slide sediments (table 1). Diversity was also significantly greater in the no plume areas ($p < .05$, fig 10).

Transplants

The racks holding PVC plates with invertebrates and algae glued to them were destroyed in winter storms. However, some of the plates remained near the study sites and examination of them 6 and 18 months later revealed an interesting trend in recruitment. At sites away from the plume (Partington Launch and Partington South) there was recruitment of encrusting corallines, fleshy red algae, Macrocystis pyrifera, other young laminarians, Ulva sp., bryozoans and barnacles (n=8). At the one plume influenced site (Big McWay) where plates remained (n=4), there was no recruitment at all. I tested this experimentally by placing 5 bare 30 cm cinder plates at Big McWay and 10 at McWay North in April 1992 (5 extra were added so that if growth occurred here young recruits could be transplanted to Big McWay). Plates collected 6 months later were still essentially bare at both sites with small amounts of serpulids and encrusting bryozoans recruiting to all.

After 3 months all Tethya aurantia placed on plates in the plume (Big McWay) and outside the plume (McWay North) appeared healthy, except those at Big McWay were covered with sediment and benthic diatoms. Unfortunately, after 10 months most sponges had moved off of plates naturally or were torn off by winter storms . It is interesting to note, however, that the 2 sponges remaining at McWay North after 10 months were healthy while the 6 sponges remaining at Big McWay were covered as before and 2 of these were unhealthy (less robust and turning from bright orange to dull brown/yellow). Balanophyllia elegans were placed on plates at these 2 sites as well, and those that remained set in the glue at Big McWay survived after 3 months, while many of those remaining at McWay North were dead (bleached coral, no live animal present). Ten months later more had been dislodged from the glue but the same pattern persisted.

After 3 months no young plants were found at either McWay North or Big McWay where Macrocystis pyrifera sporophylls were placed. Only two young plants were found in one replicate at McWay North 10 months later, but none was found in other replicates at this or the Big McWay site.

Plates with young geniculate corallines were placed at Partington Launch and Big McWay. After 10 months the plates at Big McWay lost all geniculate coralline cover while those at Partington Launch remained and grew from the bumpy crusts to 1.5-3cm tall geniculate corallines. The difference in cover was significant ($p < .05$).

After one year boulders transplanted to all sites had either been rolled by surge, buried by sand or were missing from the site all together. Those found were mostly bare rock or covered with encrusting coralline crusts, even in the control areas. Probably those boulders large enough to resist rolling in heavy surge are too large for divers to manipulate. Rock movement in this area has been seen as deep as 23 m indicating the dynamic nature of this coast (Seltenrich et al. 1980). Dayton et al. (1989) noted boulders as large as 2.5 m long were moved during heavy storm activity in San Diego in 1988.

Sedimentation/Plankton

Sediment tubes were checked 8 days after deployment and no sediment had accumulated at any site. The tubes and the racks onto which they were placed were then destroyed in winter storms so no data on sediment settling rates were available. Generally, the volume of suspended material in the plume decreased as one moved away from the slide base. Specifically, the surface volume at Little McWay (nearest slide base) was 2.12 mg/l, at Big McWay (midway) was 0.96 mg/l and at McWay North suspended material persisted but at a lower level (0.75 mg/l). Even in Partington cove, which was more than 0.8 km north of the plume and never had a visible plume of its own, the volume of suspended material, while being lower, still existed (0.65 mg/l). Percent transmittance was negatively correlated to the volume of suspended material in the water column; the more suspended material the lower the % transmittance (R squared= .993, $p<.01$). The same trend existed for samples taken at depth, but values were lower (i.e., Big McWay 0.570 mg/l and McWay North 0.420 mg/l).

Plankton tows through the plumes at both McWay and Torre Canyon Slides showed that many of the sessile invertebrates considered in this study were available for recruitment and in numbers consistent with normal availability for this time of year (Gaines et al. 1985, Raymont 1983, Table 2). There was little difference between samples taken inside and outside the plume area. Diversity (total species number) and abundance were low for the 1992 samples and all were dominated by copepods.

Cliffside photos revealed that slides with large boulders at their bases (armored) usually had no plumes while those with sandy beaches (unarmored) did ($p< .05$, Table 3). Aerial photos from the past 50 years (Table 4) showed the persistence of landslides and their associated plumes in the areas under investigation and at one site farther south. Revegetation of a slide without armoring also appeared to help reduce sediment plume size.

Plume areas were calculated from aerial photos. The densest part of the plume at McWay slide measured 21,577 m^2 (12,433 + 9,144 m^2 because plume is divided by McWay Rocks, fig 11). The maximum plume size seen at McWay during this study was 96,792 m^2 (fig 12). The Torre Canyon Slide plume area was 48,172 m^2 (fig 13). Using a gray scale on these same photos, an estimate of suspended material was correlated with each gradation in the gray scale based on known measurements taken in specific areas. From these estimates the densest area of the surface plume contained 3.05 mg/l suspended material (1.6 mg/l at Big McWay, fig 14) while the least dense area was 0.5 mg/l (0.60 mg/l at McWay North, fig 14). At depth, the corresponding values were 1.30 mg/l maximum (0.462 mg/l at Big McWay, fig 15) and 0.164 mg/l minimum (0.24 mg/l at McWay North, fig 15).

DISCUSSION

The percent sediment cover and suspended material volume (mg/l) was greater at sites within the plume and may be what limited the cover of geniculate corallines, sessile invertebrates and total biomass in the kelp forest assemblage (photo 5). The insignificant differences found between plume and no plume sites when determining biomass for individual groups may be a result of the small sample size. When an intertidal habitat was inundated with sediment, Seapy and Littler (1982) also noted a reduction in geniculate coralline cover (Corallina sp.). Geniculate corallines are generally found in less disturbed areas (Littler and Littler 1984). Transplanted young corallines were unable to survive in the plume, probably because of reduced light and/or abrasion by scour since there was more suspended material in the water column. On the other hand, encrusting corallines were generally more abundant in the plume and have been known to survive 5 months of complete burial (Miles and Meslow 1990). Perhaps because of their crustose morphology, they have adaptations to tolerate sedimentation (Steneck and Paine 1986).

Sessile invertebrates are impacted by sedimentation in many ways. A thin veneer of sediment can clog sponge ostia. Encrusting bryozoans cannot reach feeding appendages above intrusive sediment. Colonial tunicates may be smothered under a mild sedimentation regime. All may be scoured from boulder surfaces. These explain why there were generally fewer sessile invertebrates in the plume. Eckman and Duggins (1991) found that sediment accumulates below understory kelp, and that 2 bryozoan spp., 1 sponge sp. and 1 serpulid sp. were negatively affected by this sedimentation through slower growth, but mortality did not increase. Barnacles which have opportunistic life histories were more abundant in the sediment disturbed areas and were probably taking advantage of the open spaces created there (Ayling 1981, Seapy and Littler 1982). Transplanted Balanophyllia elegans may be capable of rejecting sediment particles contributing to their survival in the plume (Johannes 1976, Rogers 1990). Mobile predators probably move away from the plume disturbed areas and their absence may enhance survivorship of certain species (Menge and Sutherland 1987, Menge and Farrell 1989). These same predators may be responsible for the reduced numbers of transplanted B. elegans survivors outside the plume, although there are no known predators of B. elegans.

Some fleshy red algae appeared to tolerate plume sediment. These, perhaps, were taking advantage of reduced competition for space. However, low fleshy red biomass has also been seen in the presence of sand (Breda 1982). Many of the fleshy red algae found at plume influenced sites were species capable of tolerating polluted waters or those able to quickly colonize available space after a disturbance such as a winter storm (Dawson and Foster 1982). Specifically, there were more Callophyllis sp. and Rhodymenia sp. at Big McWay (13.33 ± 3.96 %) than at McWay North (1.67± 1.12%).

Macrocystis pyrifera is dependent on light (Dean and Jacobsen 1984, Miles and Meslow 1990, Rosenthal et al. 1974) but can undergo gametogenesis at relatively low light levels (Deysher and Dean 1986). Total cover of brown algae (mostly laminarians) was generally lower in the plume areas. Recruitment from transplanted sporophylls was low at all sites but it is possible that all sporophylls were consumed by grazers prior to spore dispersal or that conditions were just not right for recruitment. The plume at the Portuguese Bend landslide did not reduce light penetration to substrate enough to inhibit M. pyrifera production, but there were no kelp where turbity and sediment cover were the highest (Stephens 1990). M. pyrifera generally are not resistant to sediment disturbance (Devinny and Volse 1978); however, the cover of these plants in particular did not differ between sites in this study.

Sedimentation generally reduces recruitment by inhibiting settlement, scouring new sessile recruits and smothering or inhibiting feeding of new recruits (Daly and Mathieson

1977, Duggins et al. 1990, Gotelli 1988, Jackson 1979). Most species of sessile invertebrates and algae need a clean, firm surface on which to settle (Giese and Pearse 1974). Species with photopositive larvae may be inhibited by turbid water (Buss 1979). However, some bryozoans and ascidians are indifferent to light (Thorson 1964) and it is unknown whether those in Big Sur fit into this category. Recruitment that happened to occur on PVC plates was much greater at sites away from the plume. It is interesting that settlement was negligible on cinder plates at both sites when others have found that taxa like tunicates settle in all seasons (Carwile 1989). However, most settle in summer and early fall so it is possible that recruits in the control area were not yet visible at the time of sampling. This could explain the increased settlement on PVC plates which were sampled in spring rather than fall. 1992 was an El Nino year, which may be the reason for the large decrease in plankton abundance and diversity which may have led to limited growth on recruitment plates. It is also possible that the zooplankton bloom occurred early, eliminating diatoms and other smaller zooplankton. Also immersion time and duration may have been inadequate since the PVC plates were immersed for same amount of time but over winter.

It is generally accepted that moderate disturbance increases diversity by reducing competition and reducing monopolization of space by competitive dominants (Ayling 1981), allowing early and late successional species to coexist (Sebens 1985). Low disturbance permits monopolization of space by dominants and decreases diversity and high continuous disturbance decreases diversity since only opportunistic or stress tolerant forms will survive (Sebens 1985). In this study, diversity was greater in areas without plumes, which suggests some low level disturbance always affects this area of the coast. This may be sedimentation or scour, since sediment still exists at these sites (fig 2). Heavy surge and wave action may also act as a low level disturbance by turning boulders or ripping organisms from substrate. The comparatively low diversity in the plume suggests that this was a large disturbance where we would expect to find more opportunistic or stress tolerant forms (like fleshy red algae).

McWay and Torre Canyon Slides, sites with sediment plumes, had a reduced number of species present, reduced biomass, and lower percent cover of intolerant forms like sessile invertebrates and geniculate corallines. These differences are probably correlated to the greater amount of suspended material associated with the plumes. These plumes can be reduced or eliminated as slides age, becoming armored and revegetated. Revegetation reduces erosion and armoring stabilizes the base of the slide. Big Sur has a highly erosional coast. Along a 27 km stretch, 26 slides were counted on the coastal side of Highway 1, and 65% of these had plumes associated with them. Landslides, therefore, may play an important role in structuring the marine environment in Big Sur.

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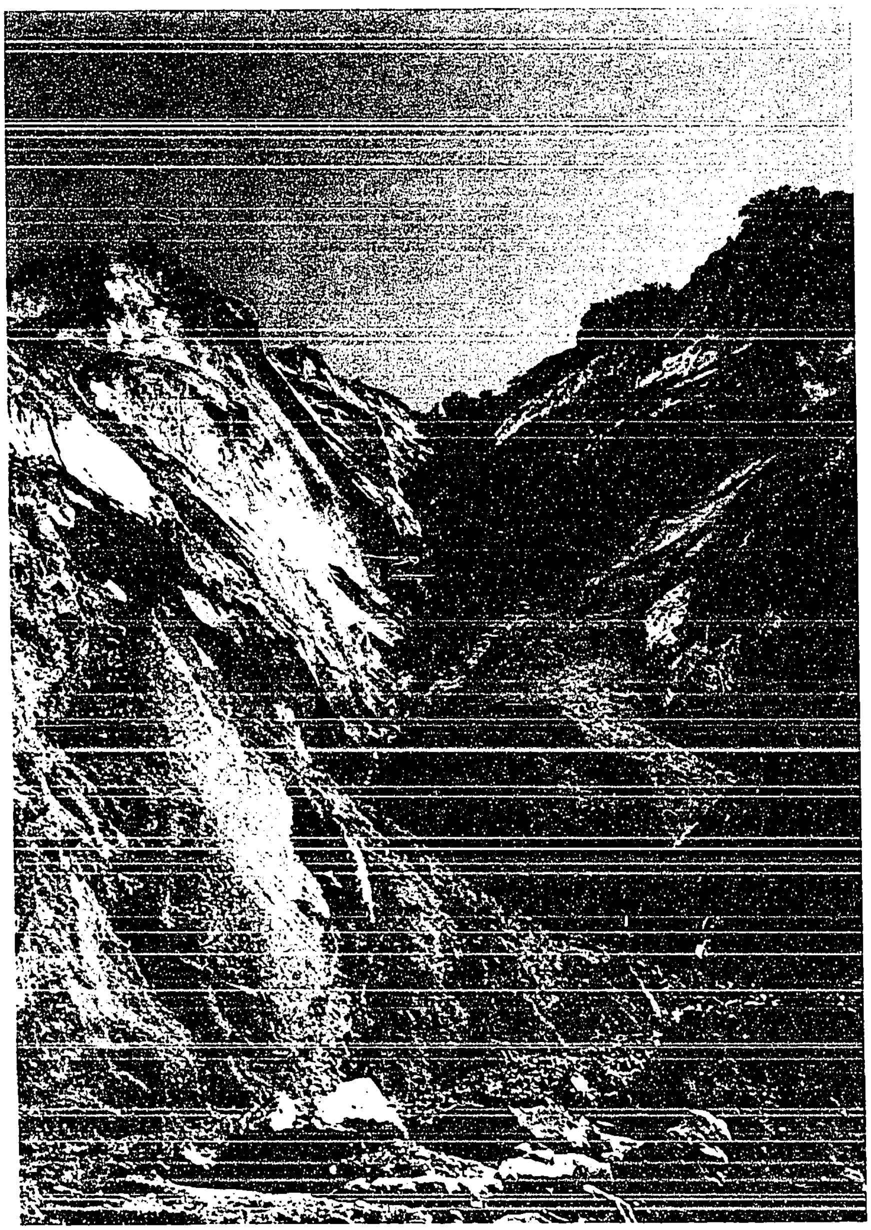
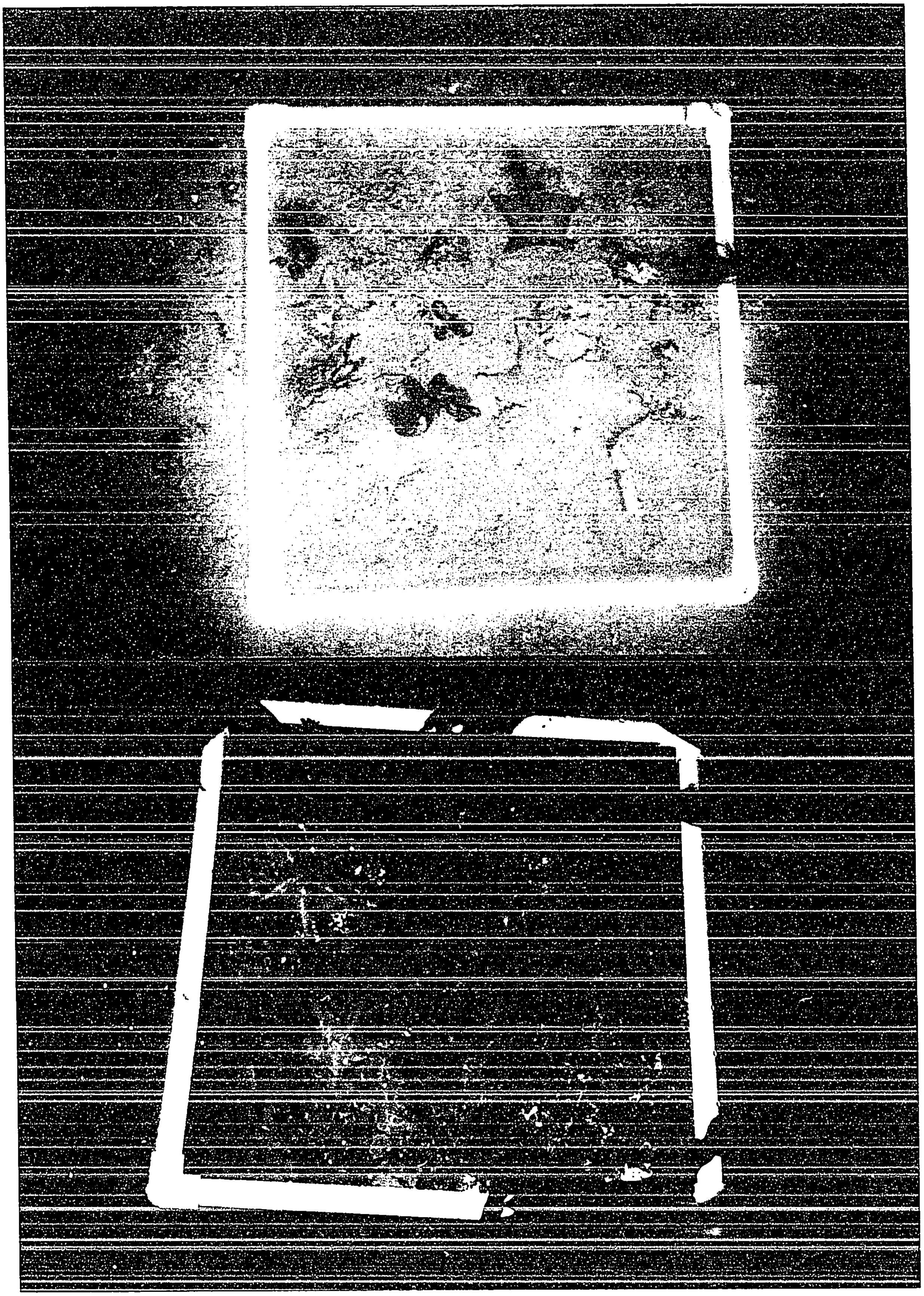
LIST OF PHOTOS





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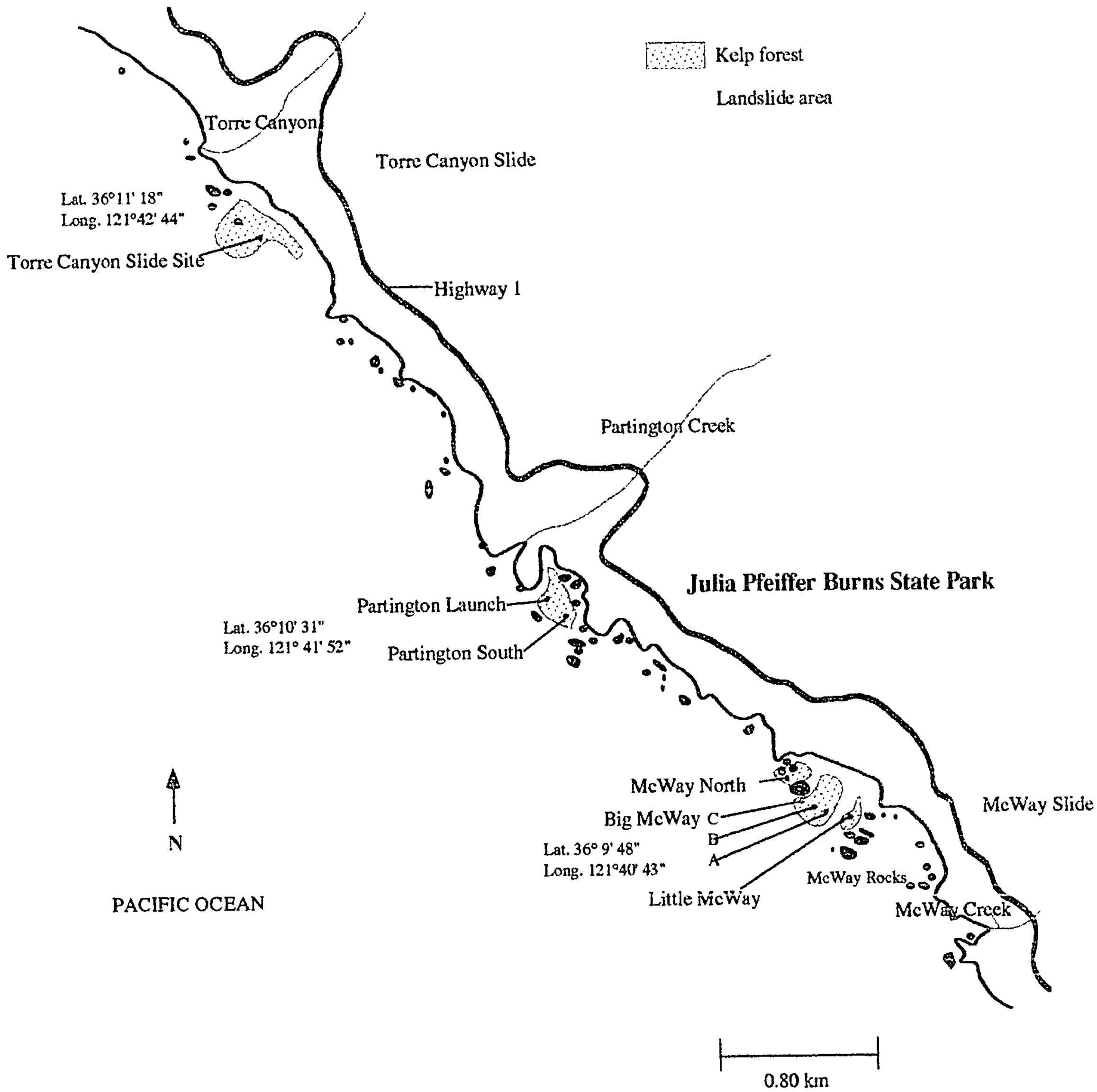
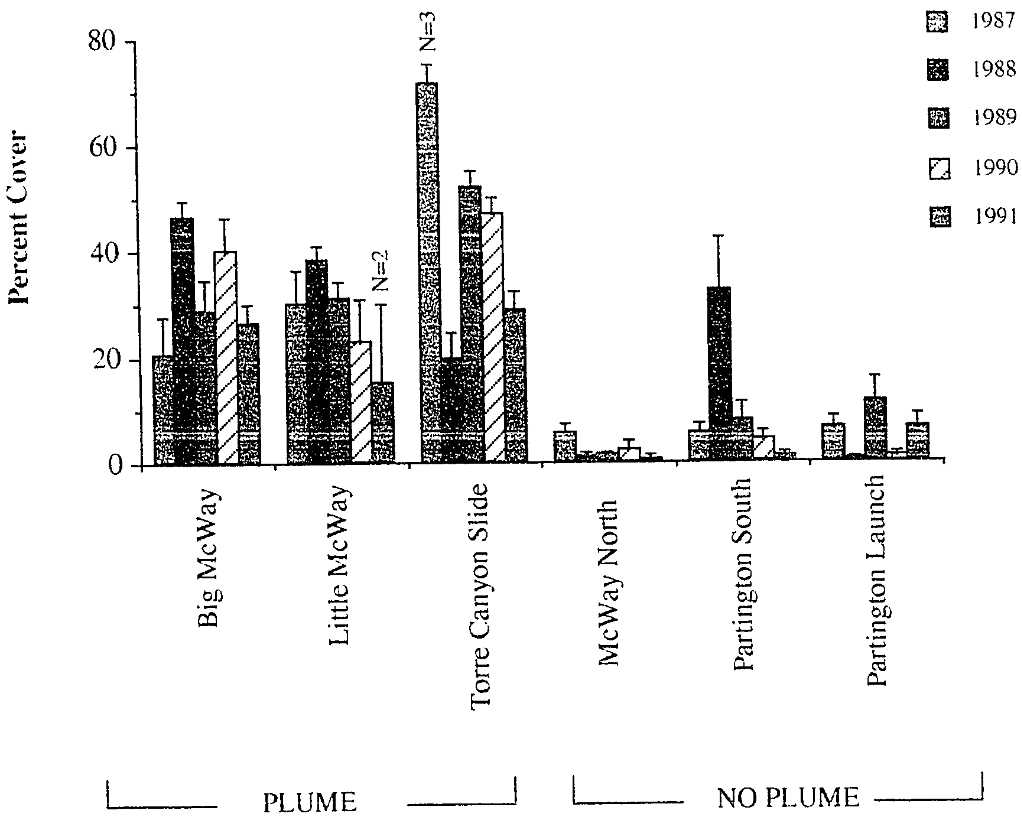
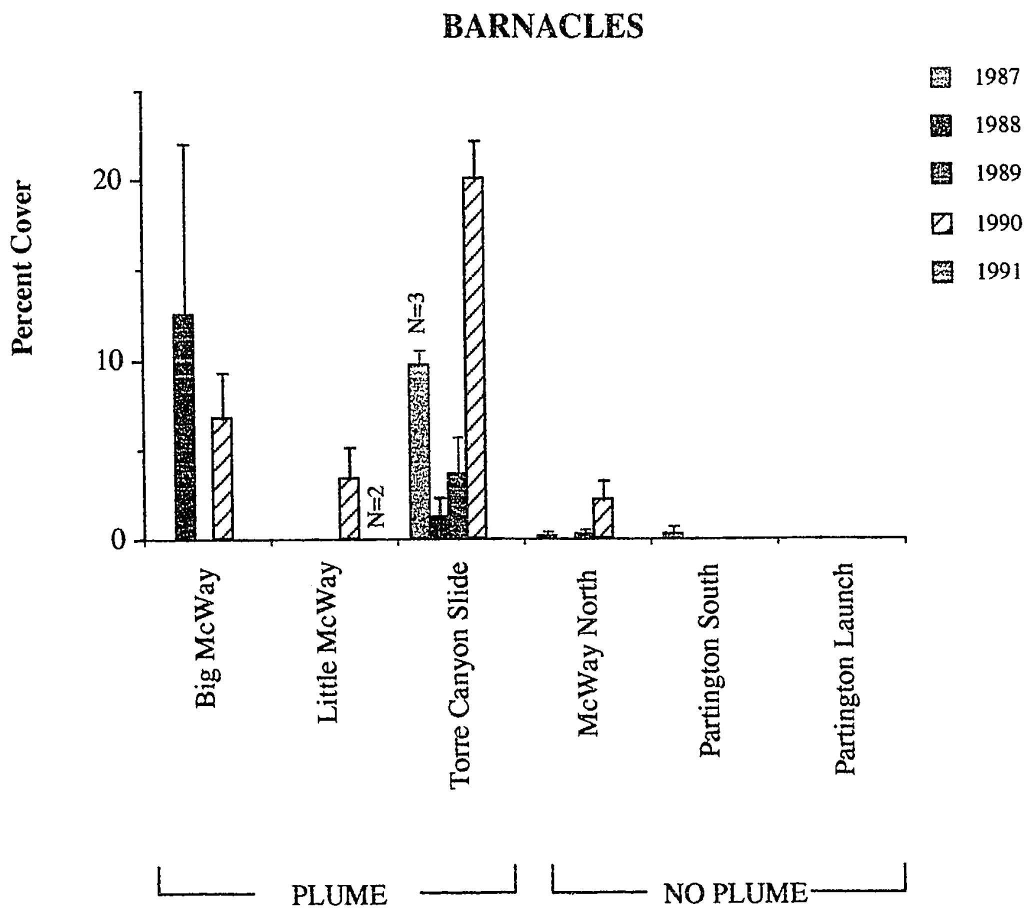
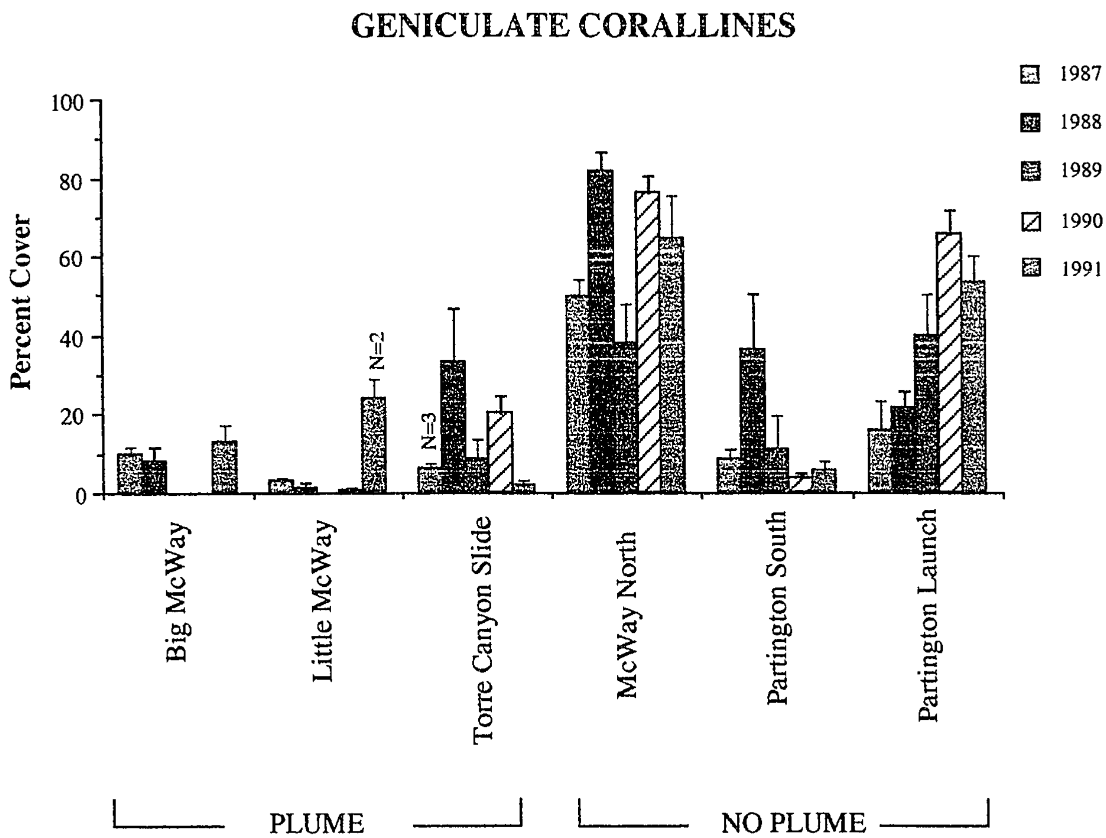

Kelp forest
Landslide area
Torre Canyon
Torre Canyon Slide
Lat. 36°11' 18"
Long. 121°42' 44"
Torre Canyon Slide Site
Highway 1
Partington Creek
Julia Pfeiffer Burns State Park
Partington Launch
Lat. 36°10' 31"
Long. 121° 41' 52"
Partington South
N
PACIFIC OCEAN
McWay North
Big McWay C
B
A
Lat. 36° 9' 48"
Long. 121°40' 43"
Little McWay
McWay Rocks
McWay Creek
McWay Slide
0.80 km

SEDIMENT


Percent Cover
80
60
40
20
0
N=3
N=2
1987
1988
1989
1990
1991
Big McWay
Little McWay
Torre Canyon Slide
McWay North
Partington South
Partington Launch
PLUME
NO PLUME

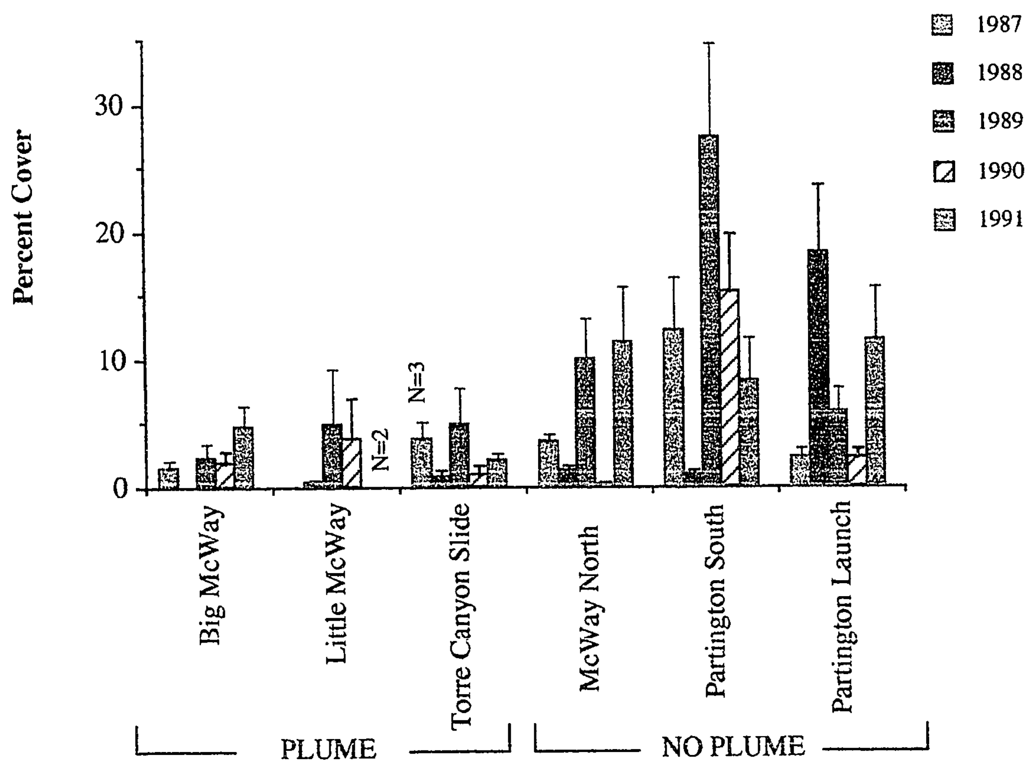


BARNACLES
1987
1988
1989
1990
1991
Percent Cover
20
10
0
N=2
N=3
Big McWay
Little McWay
Torre Canyon Slide
McWay North
Partington South
Partington Launch
PLUME
NO PLUME

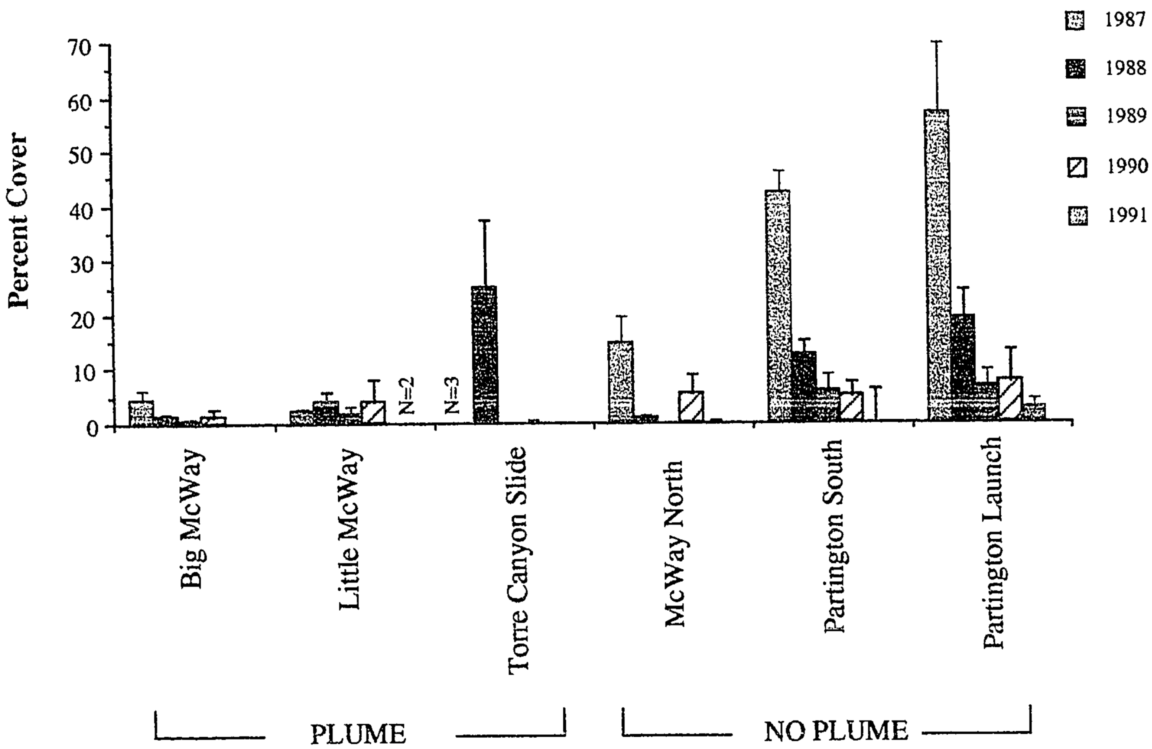


GENICULATE CORALLINES
1987
1988
1989
1990
1991
Percent Cover
100
80
60
40
20
0
N=2
N=3
Big McWay
Little McWay
Torre Canyon Slide
McWay North
Partington South
Partington Launch
PLUME
NO PLUME

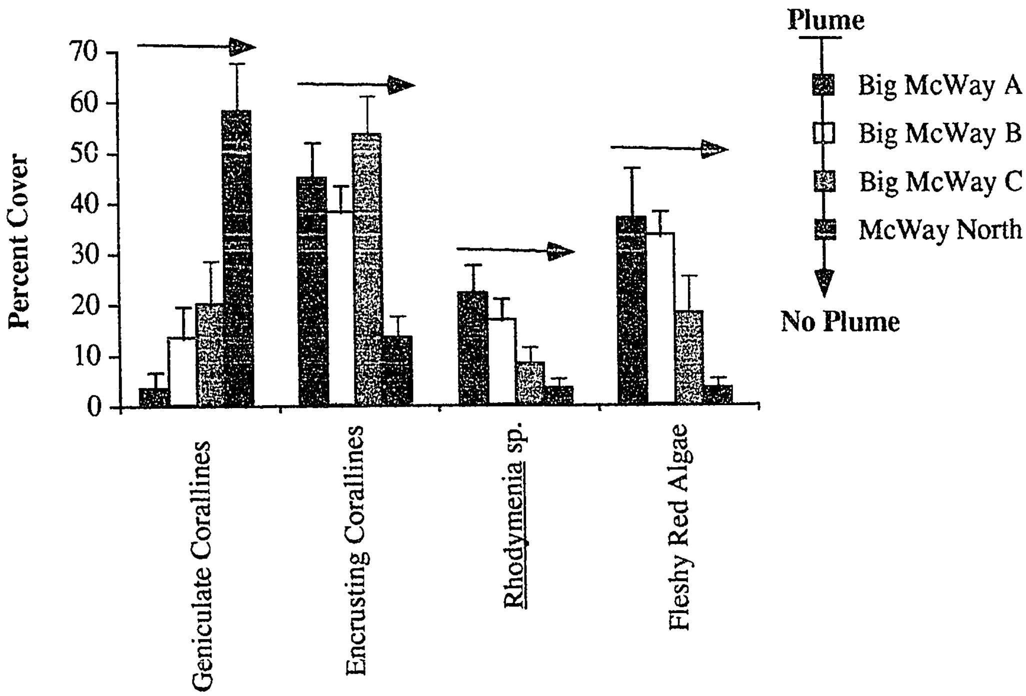
SESSILE INVERTEBRATES

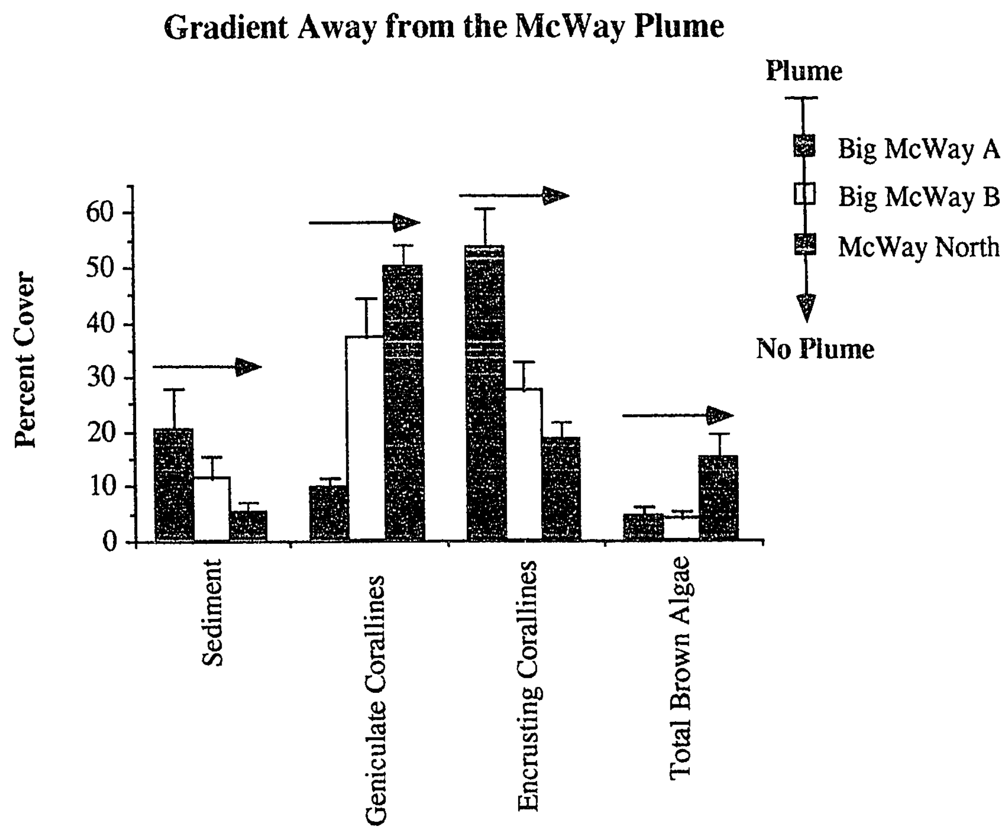


TOTAL BROWN ALGAE

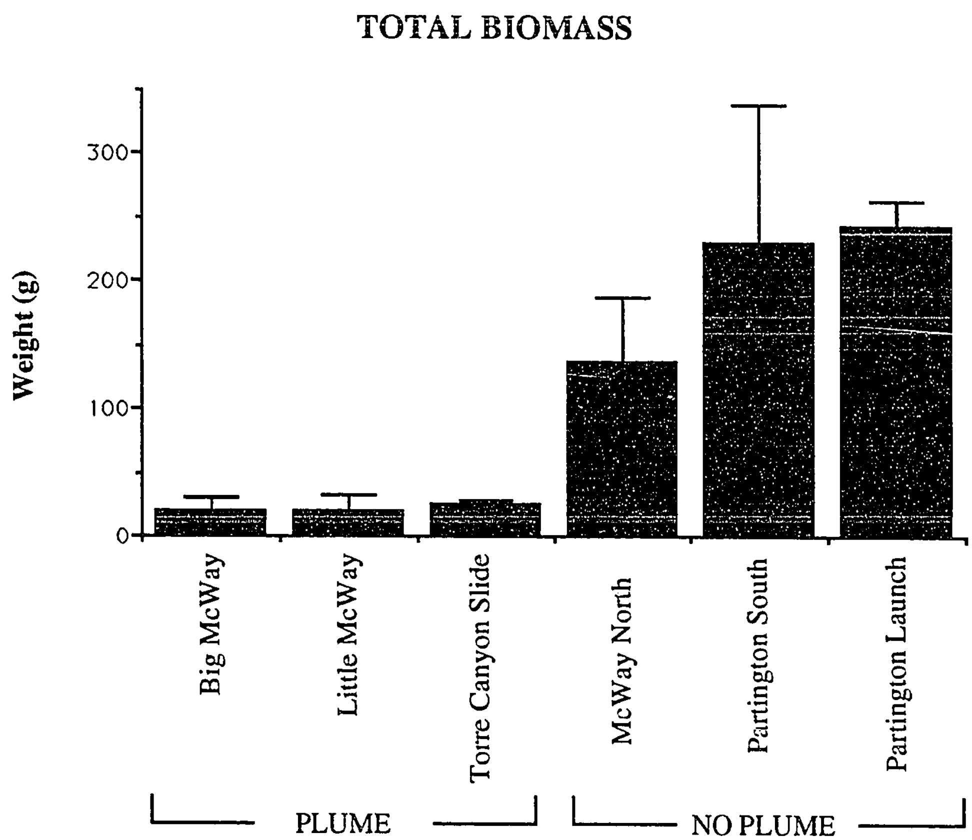


Gradient Away from the McWay Plume

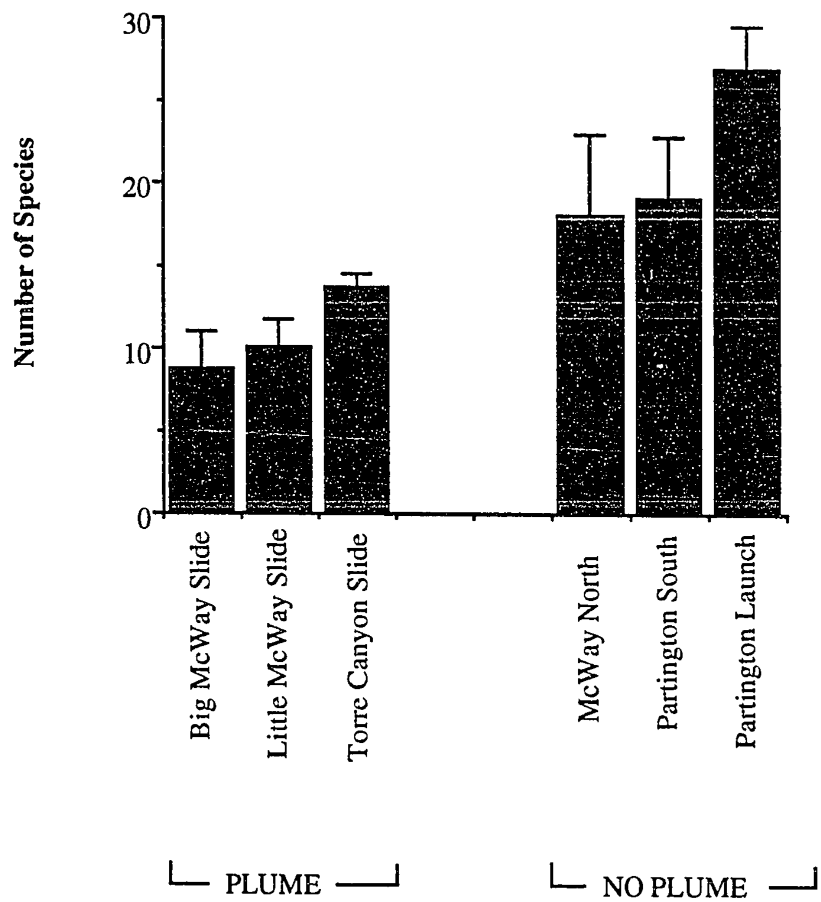




Gradient Away from the McWay Plume
Plume
Big McWay A
Big McWay B
McWay North
No Plume
Percent Cover
60
50
40
30
20
10
0
Sediment
Geniculate Corallines
Encrusting Corallines
Total Brown Algae


TOTAL BIOMASS
Weight (g)
300
200
100
0
Big McWay
Little McWay
Torre Canyon Slide
McWay North
Partington South
Partington Launch
PLUME
NO PLUME

DIVERSITY


Number of Species
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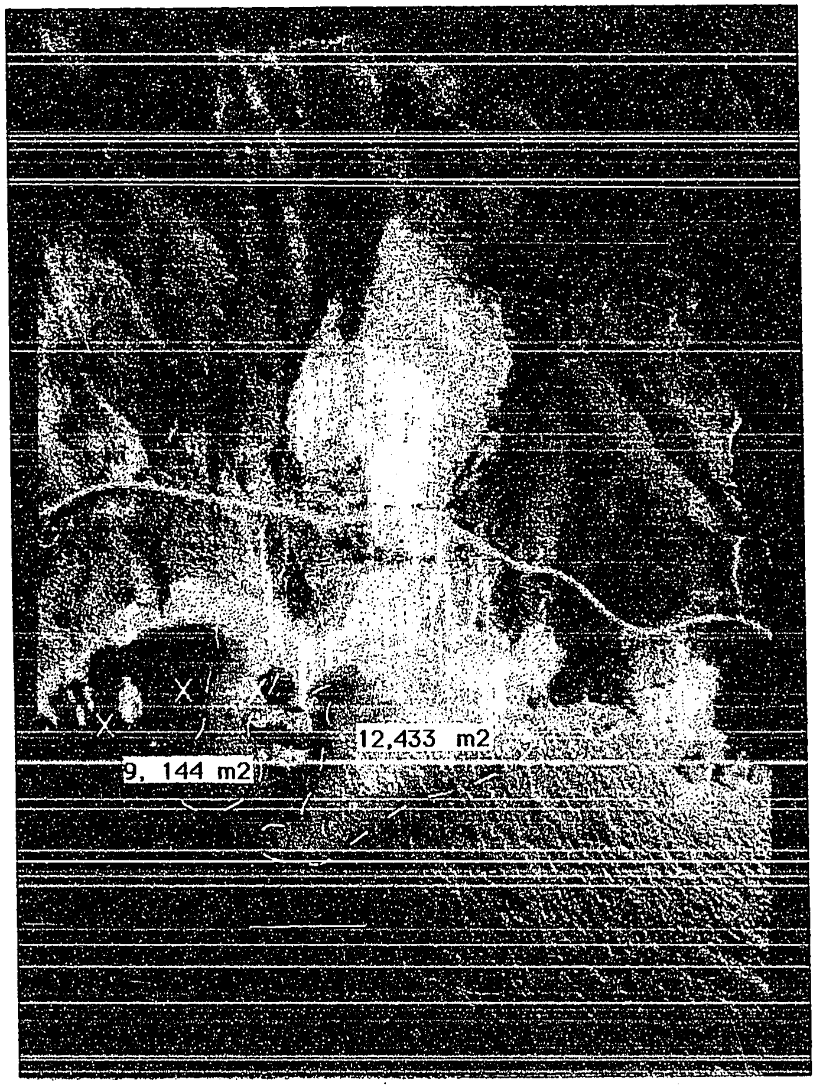
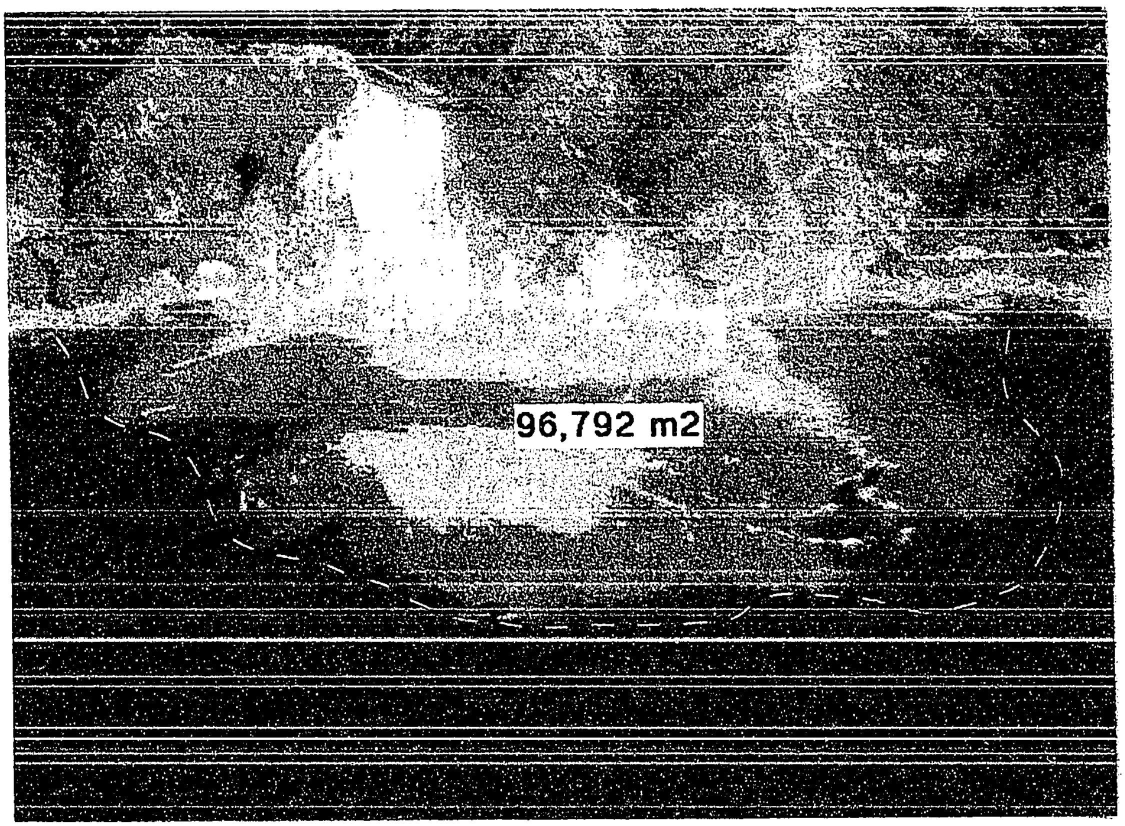
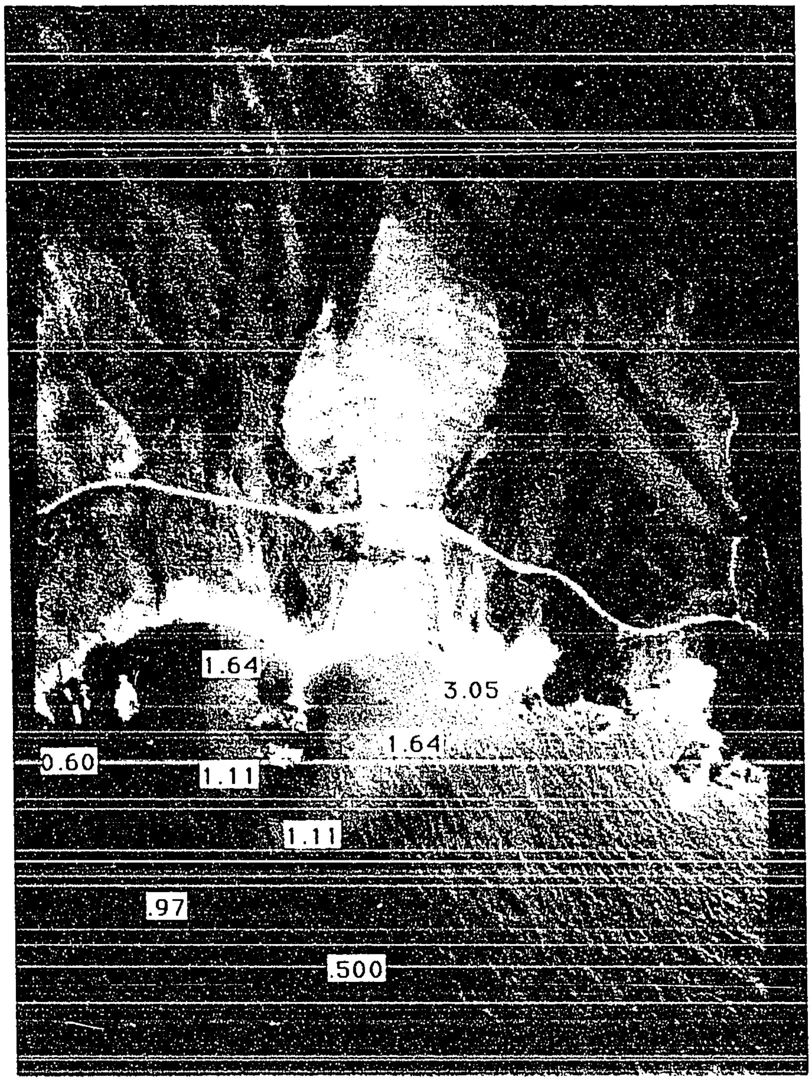
20
10
0
Big McWay Slide
Little McWay Slide
Torre Canyon Slide
McWay North
Partington South
Partington Launch
PLUME
NO PLUME


12,433 m2
9, 144 m2


96,792 m2


48,172 m2


1.64
3.05
0.60
1.64
1.11
1.11
.97
.500


0.46
1.30
0.24
0.46
0.73
0.39
0.16

Table 1. Biomass for particular animal and algal groups at 3 sites not influenced by sediment plumes (McWay North, Partington South, Partington Launch) and 3 sites influenced by sediment plumes (Little McWay, Big McWay, Torre Canyon Slide=T.C. Slide). Samples were obtained by taking 3 replicate 0.125 m2 destructive samples at each site. Mean number and standard error ( ) are given in grams.

	NO PLUME			PLUME		
	McWay North	Partington South	Partington Launch	Big McWay	Little McWay	T. C. Slide
Sponges						
Bryozoans	.47 (.41)	153.07 (69.04)	63.8 (29.21)	0	.02 (.02)	0
Tunicates	31.05 (21.15)	7.93 (6.42)	2.3 (1.43)	.37 (.43)	.07 (.09)	3.8 (2.85)
Balanophyllia	4.6 (6.13)	6.5 (9.19)	9.5 (6.72)	.20 (.29)	.85 (1.05)	0
	0	.25 (.35)	0	2.11 (2.98)	0	1.50 (2.12)
Crustaceans						
Barnacles	.52 (.45)	.28 (.22)	3.13 (1.74)	.04 (.04)	.15 (.15)	.06 (.04)
	7.4 (8.27)	0	.03(.05)	4.87 (3.53)	.12 (.15)	1.17 (.73)
Fleshy Red Algae						
Articulated Corallines	4.11 (5.65)	13.25 (18.10)	41.8 (36.77)	4.11 (3.11)	1.78 (1.22)	3.4 (4.49)
Brown Algae	20.61 (28.77)	2.77 (2.47)	60 (51.98)	4.63 (3.13)	1.20 (1.58)	9.55 (2.12)
	0	1.40 (1.84)	14.13 (19.71)	.22 (.32)	14.19 (12.48)	.04 (.06)
Sipunculids						
Worms	.90 (.73)	.25 (.20)	.03 (.05)	0	0	.02 (.03)
Molluscs	.77 (1.01)	.69 (.34)	1.07 (.17)	0	.06 (.05)	.37 (.45)
Echinoderms	.09 (.04)	2.81 (3.14)	2.23 (1.18)	.55 (.76)	.07 (.05)	.39 (.23)
Unknowns	.21 (.21)	.41 (.33)	2.57 (2.85)	0	0	0
	64.66 (45.18)	50.1 (29.73)	40.97 (32.69)	.96 (.94)	.47 (.66)	4.43 (1.43)

Table 2. Totals from three plankton tows taken in the central plume area of 2 large slides (McWay and Torre Canyon Slides) in 1990 and 3 taken inside and outside the plume at McWay in 1992. Only larvae that may become sessile invertebrates focused on in this study were counted (approximate mean number/5min tow). Copepod numbers are shown to compare years. Other groups present are also shown here. Medusae are probably mostly holoplanktonic.

1990

TORRE CANYON SLIDE

	Number/5min tow
Polychaetes	304
Copepods	955
Veligers (Mollusca)	Present
Fish larvae	Present
Pteropd	Present
Medusa (Anthozoa)	274
Oikopleura	Present
Shrimp	Present
Bivalve	Present
Fish eggs	Present
Mysids	Present
Chaetognath	Present
Diatoms	Present
Bryozoan larvae	1611
Crab larvae	Present
Ostracod	Present
Nauplii (barnacle larvae)	4181

MCWAY SLIDE

	Number/5min tow
Polychaetes	255
Copepods	1300
Veligers (Mollusca)	Present
Medusa (Anthozoa)	694
Oikopleura	Present
Bivalve	Present
Mysids	Present
Chaetognath	Present
Diatoms	Present
Bryozoan larvae	2450
Crab larvae	Present
Ostracod	Present
Nauplii (barnacle larvae)	1539

1992

INSIDE PLUME

Copepods	500
Eggs	Present
Nauplii	203
Cyphonutes	50
Chaetognatha	Present

OUTSIDE PLUME

Copepods	625
Eggs	Present
Nauplii	53
Veliger	Present
Zoea	Present
Medusae	42

Table 3. The relationship between armoring of slides and the presence of a sediment plume. When fine sediments are winnowed away by surf action at the base of a slide, larger boulders remain to armor the slide. Table shows the number of slides occuring in each category.

	No Plume	Small Plume	Medium Plume	Large Plume
ARMORED SLIDES	8	5	0	0
PARTIALLY ARMORED SLIDES	1	3	3	0
UNARMORED SLIDES	0	0	1	5

Table 4. Characteristics associated with the Torre Canyon, McWay and Lucia slides. All photos were taken on one day in the year given. In some photos it was difficult to determine presence or size of some factors (?).

TORRE CANYON SLIDE

Year	Slide	Kelp	Plume	Armor
1942	Present	Present	Large	No
1949	Present	Present	Large	No
1953	Present	Present	Medium	No
1968	Slight erosion	?	Small	?
1972	Well vegetated	Present	Small	No
1976	Well vegetated	Present	Small	?
1978	Well vegetated, some erosion	Present	Large	No
1980	Well vegetated, some erosion	Present	Large	No
1985	Well vegetated	Present	Medium	?
1986	Well vegetated	Present	Small	No
1992	Well vegetated	Present	Medium	No

MCWAY SLIDE

Year	Slide	Kelp	Plume	Armor
1942	Vegetation, slight erosion	?	Small	No
1949	Vegetation, slight erosion	Present	?	?
1953	Vegetation, slight erosion	Present	Small	?
1956	Erosion	Present	Small	?
1968	Minor erosion	?	None	No
1970	Extended erosion	Present	None	?
1972	Extended erosion	?	Small	?
1976	Revegetated	Present	None	Some south of pt.
1978	Revegetated	Present	Small	Some south of pt.
1979	Revegetated	Present	Small	Some south of pt.
1980	Revegetated	Present	Small	Some south of pt.
1983	Major slide occurs	Present	Large	No
1984	Finished slide repair	Present	Large	No
1985	Major erosion	Present	Large	No
1986	North end of slide eroding	Present	Large	No
1992	South end with major erosion	Present	Large	Some north of pt.

Table 4. Continued

LUCIA SLIDE

Year	Slide	Kelp	Plume	Armor
1942	Small	?	Large	Slight
1949	3/4 of todays size	Present	Large	Slight
1953	3/4 of todays size	?	Medium	?
1956	Same as today	Present	Large	Slight
1968	Same as today	Present	Medium	Slight
1970	Same as today	Present	Medium	Slight
1972	Same as today	?	Large	?
1976	As today, slight vegetation	Present	Medium	Slight north, none south
1978	Same as today	Present	Large	Slight north, none south
1980	Same as today	Present	Large	Slight north, none south
1985	Same as today	Present	Large	Slight north, none south
1986	Same as today	Present	Medium	Slight north, none south
1992	Large slide slightly vegetated	Present	Large	Slight north, none south

APPENDIX A

BIG SUR SPECIES LIST

This list contains species identified from photographs, point contacts and destructive scrape samples.

ALGAE

Phaeophyta
- Laminariales
  - Macrocystis pyrifera
  - Pterygophora californica
  - Laminaria sp.
- Fucales
  - Cystoseira osmundacea
- Desmarestiales
  - Desmarestia ligulata var. ligulata

Rhodophyta
- Cryptonemiales
  - Corallinaceae
    - Bosiella californica
    - Calliarthron tuberculosum
    - Encrusting Corallines
  - Cryptonemiaceae
    - Prionitis lanceolata
  - Kallymeniaceae
    - Callophyllis flabellulata
    - Callophyllis violacea
- Gigartinales
  - Gigartinaceae
    - Gigartina spp.
- Rhodymeniales
  - Rhodymeniaceae
    - Rhodymenia californica
    - Rhodymenia pacifica
- Ceramiales
  - Ceramiaceae
    - Neoptilota sp.
  - Delesseriaceae
    - Cryptopleura sp.
    - Polyneura latissima
  - Dasyaceae
    - Rhodoptilum plumosum

INVERTEBRATES

Porifera
Hymenamphiastra cyanocrypta
Tethya aurantia
Acarnus erythicus
Polymastia pachymastia
Leucandra heathi
Leucilla nuttingi

Bryozoa
Heteropora magna
Hippodiplosia insculpta
Parasmittina sp.
Lagenipora californica
Phidolopora californica
Crissia sp.
Microcliona sp.

Chordata
Urochordata
Aplidium solidum
Aplidum californicum
Cystodytes lobatus
Styela montereyensis
Polyclinum planum
Archidistoma sp.

Cnidaria
Anthozoa
Balanophyllia elegans
Tealia sp.
Hydrozoa
Aglaophenia sp.
Scyphozoa
Stauromedusae

Mollusca
Gastropoda
Calliostoma spp.
Tegula sp.
Cypraea spadicea
Diodora aspera
Anisodoris nobilis
Bivalvia
Hinnites giganteus

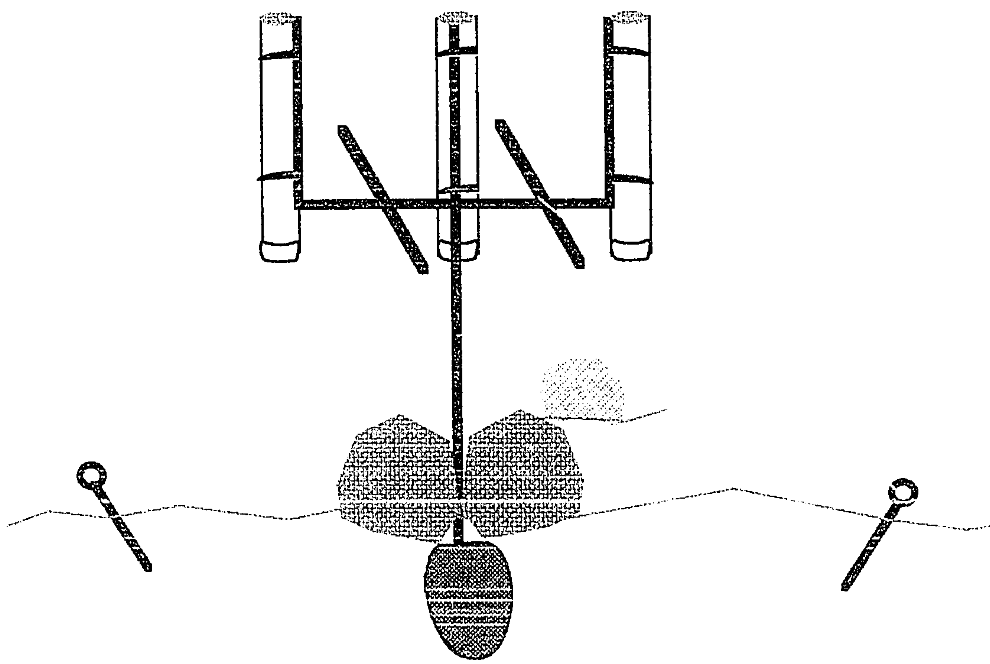
Arthropoda
Crustacea
Isopoda
Idotea sp.
Tanaidacea
Amphipoda
Caprella sp.
Amphipods
Decapoda
Loxorhynchus crispatus
Mimulus foliatus
Cancer sp.
Crangon sp.
Cirripedia
Balanus crenatus

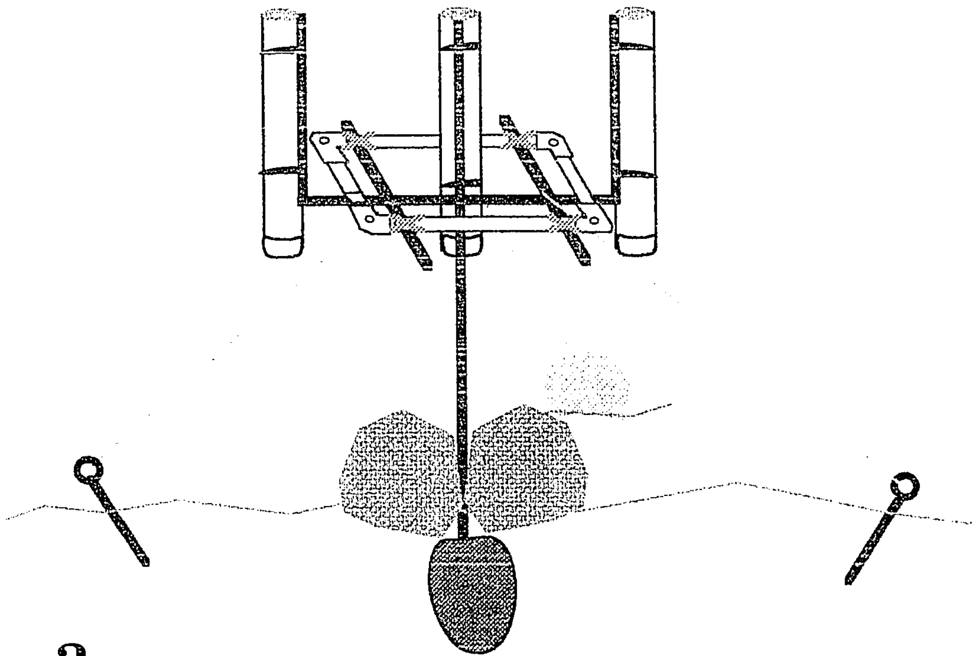
Annelida
Phragmatopoma californica
Sabella crassicornis
Salmacina tribranchiata
Eudistylia polymorpha

Sipuncula

APPENDIX B

The following are diagrams of constructed subtidal structures described in the methods (not drawn to scale).





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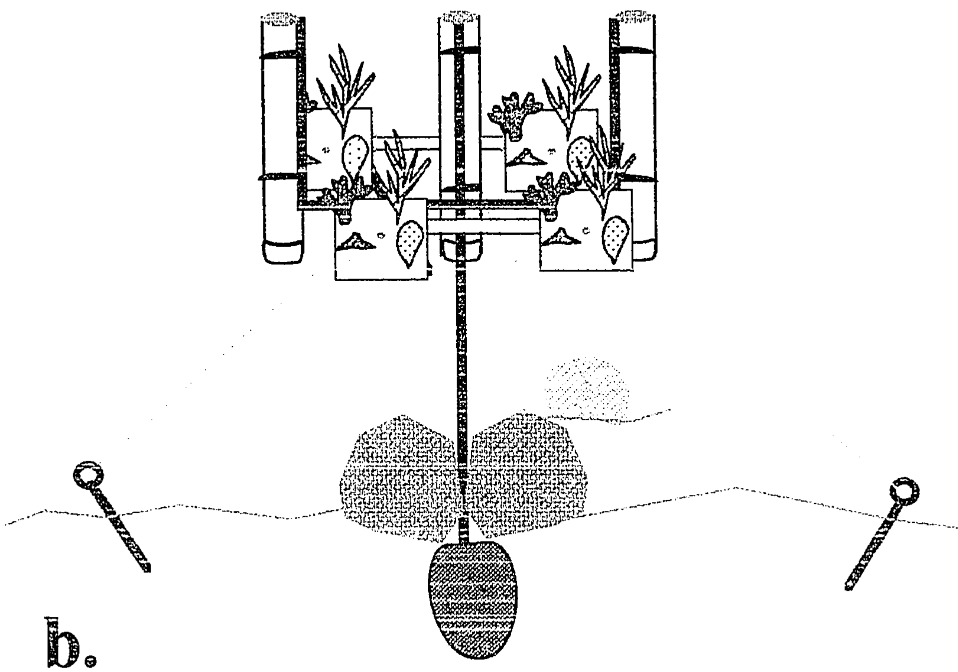

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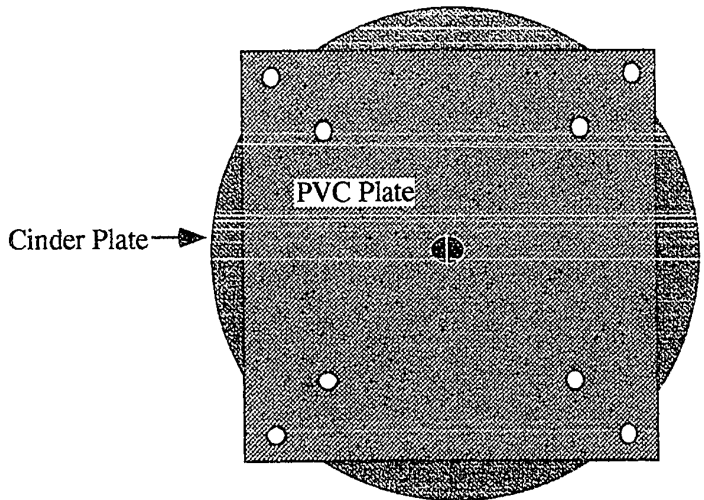

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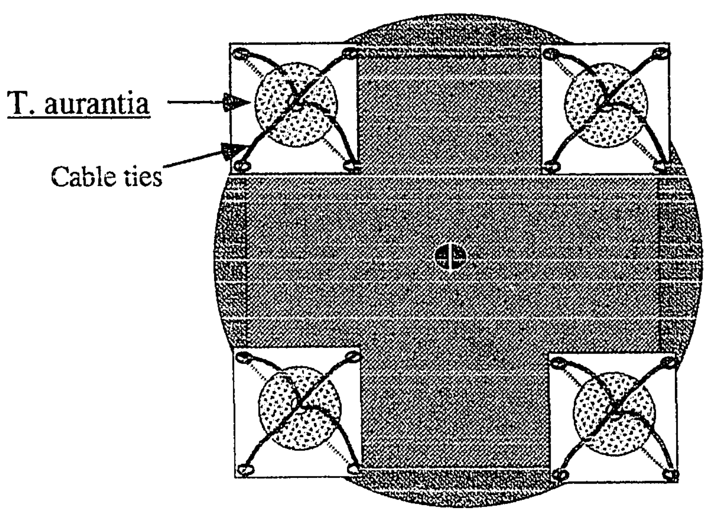

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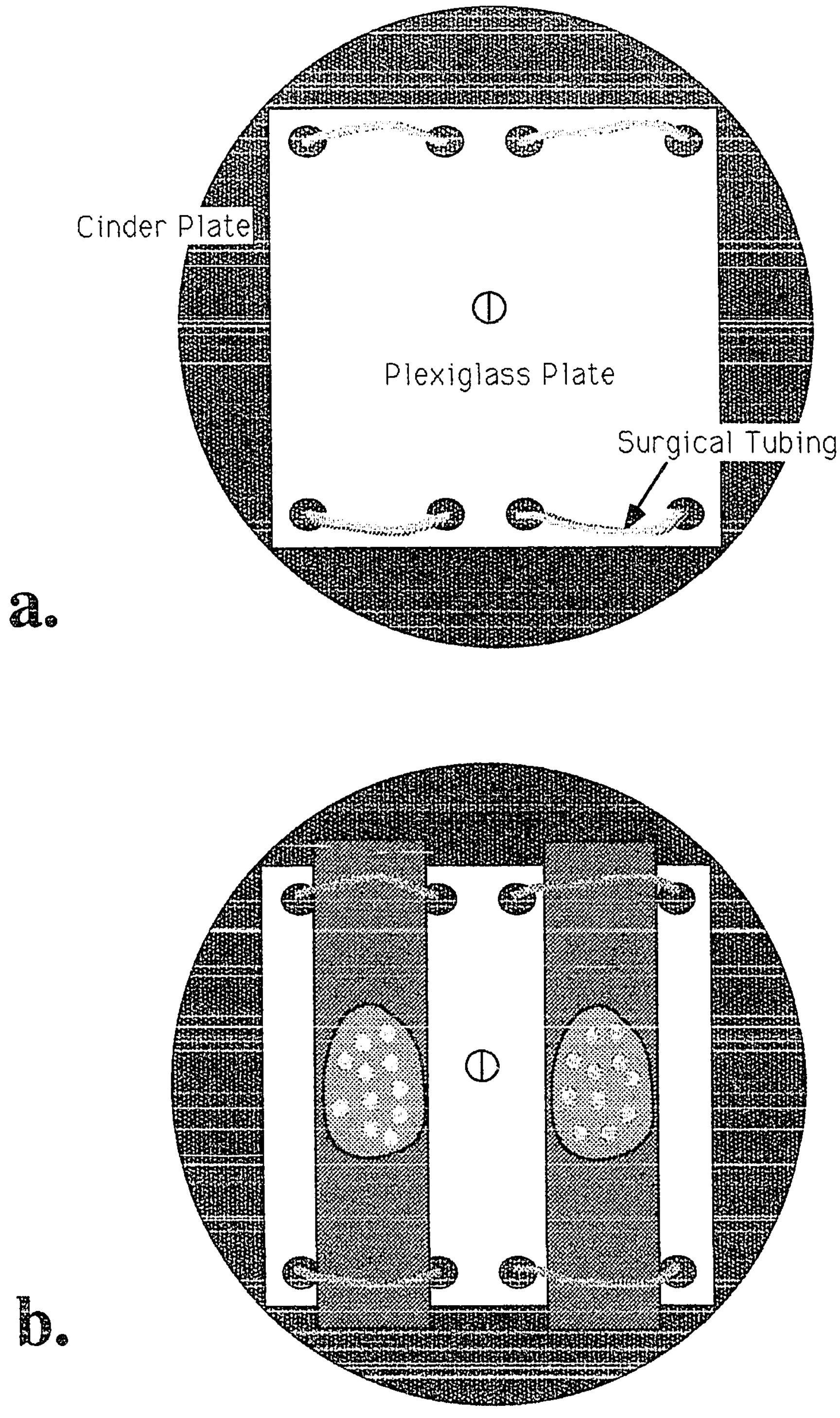
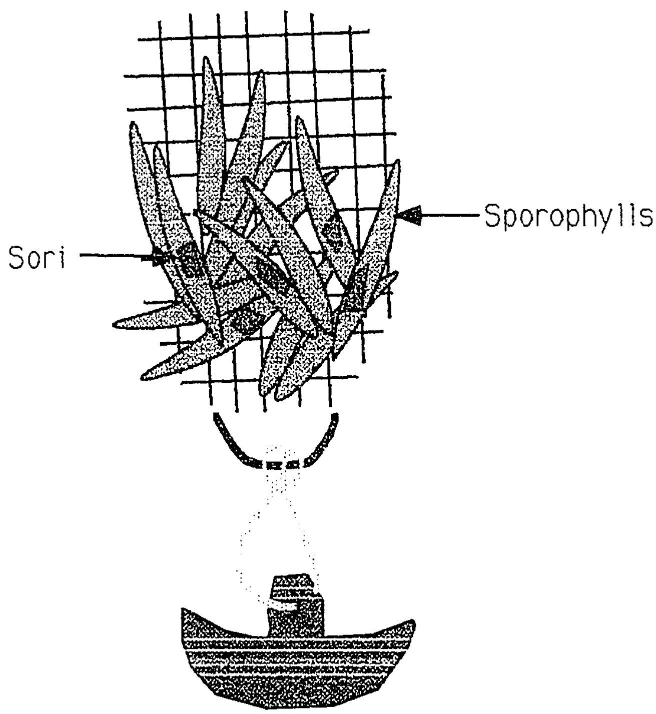

Cinder Plate
Plexiglass Plate
Surgical Tubing
a.
b.

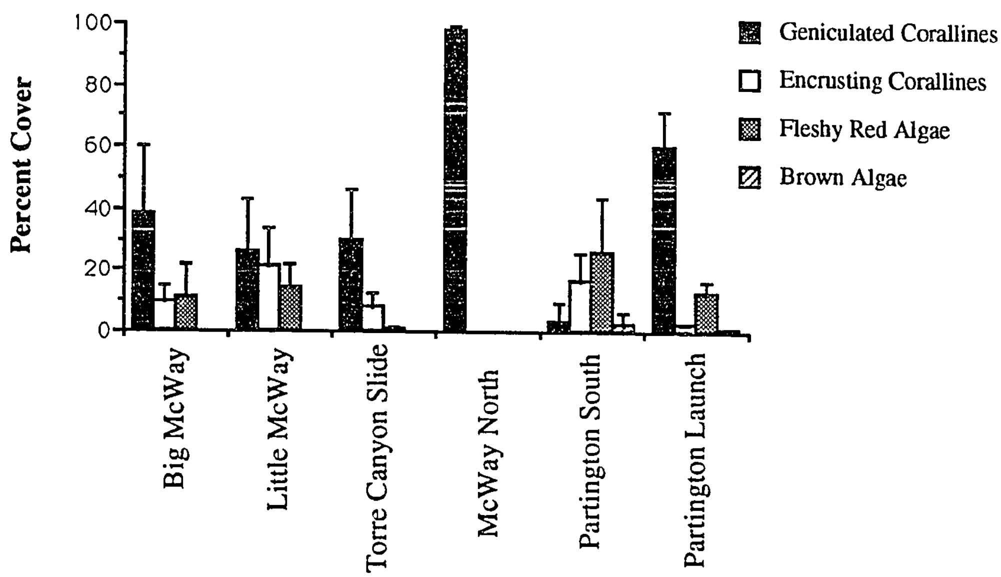

Sori
Sporophylls

APPENDIX C

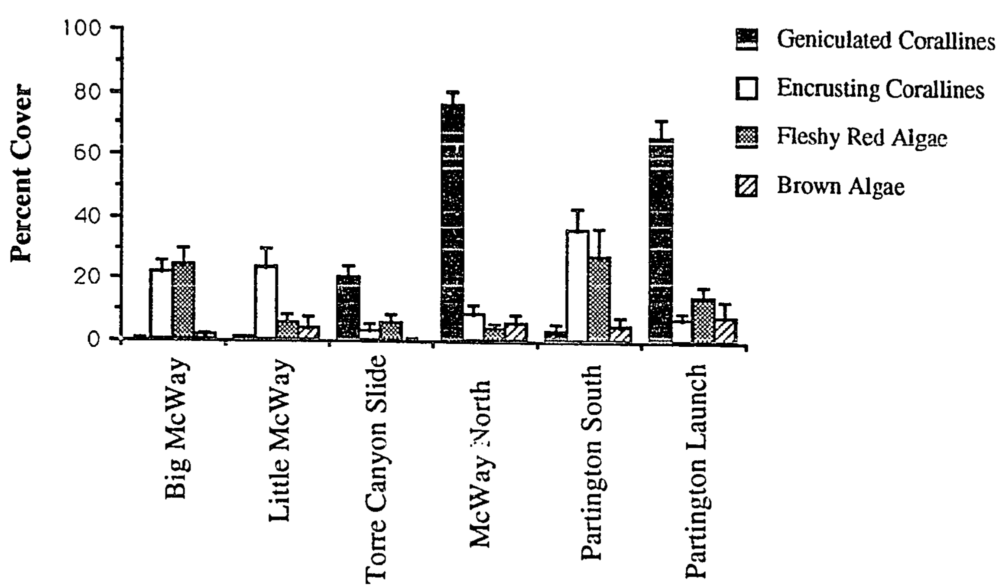
All items in Appendix C are comparisons of subtidal techniques. Overall, the $0.25m^2$ photo quadrats were more efficient and provided the most comparable data. Clipping away understory algae is time consuming and unnecessary. Percent cover of all organisms fluctuate annually and seasonally. To eliminate some variability only photographs taken in the fall were compared from year to year.

PAGE

CLOSE-UP QUADRAT



0.25 m2 QUADRAT



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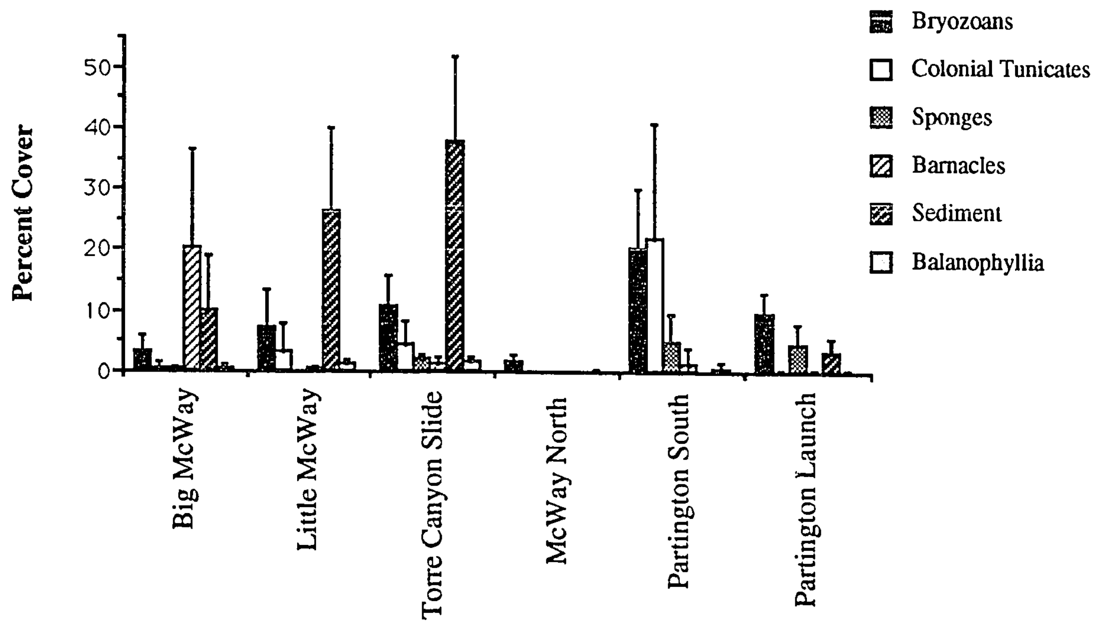

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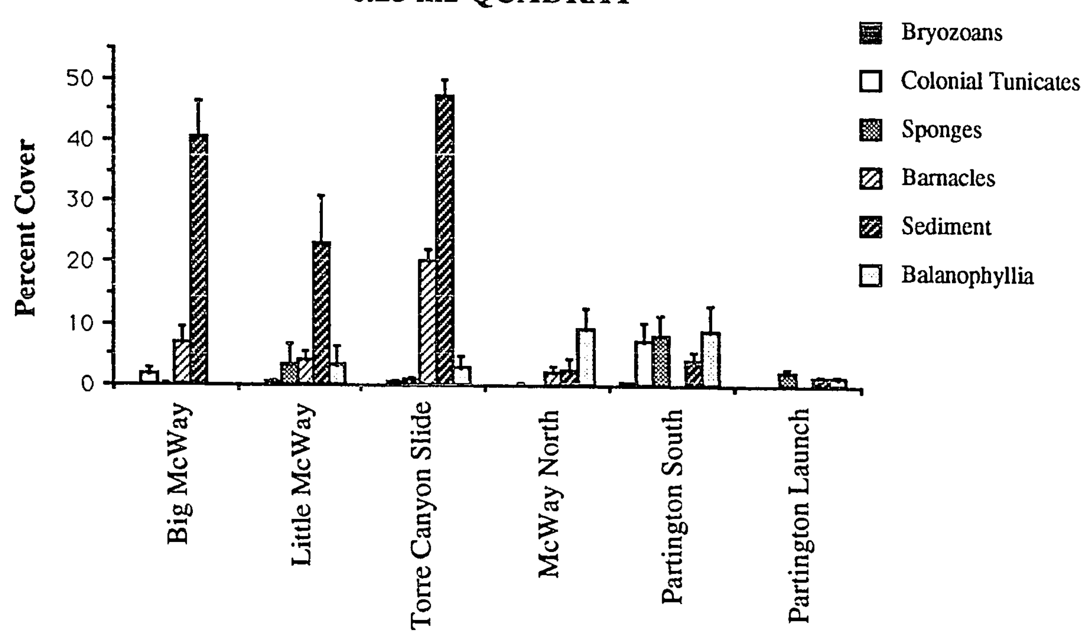


POINT QUADRAT

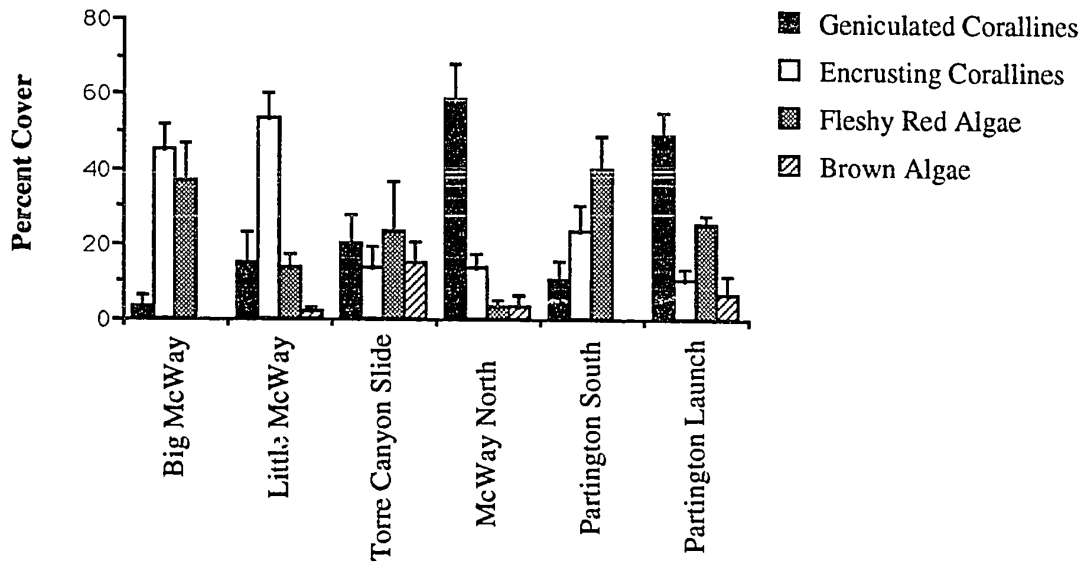
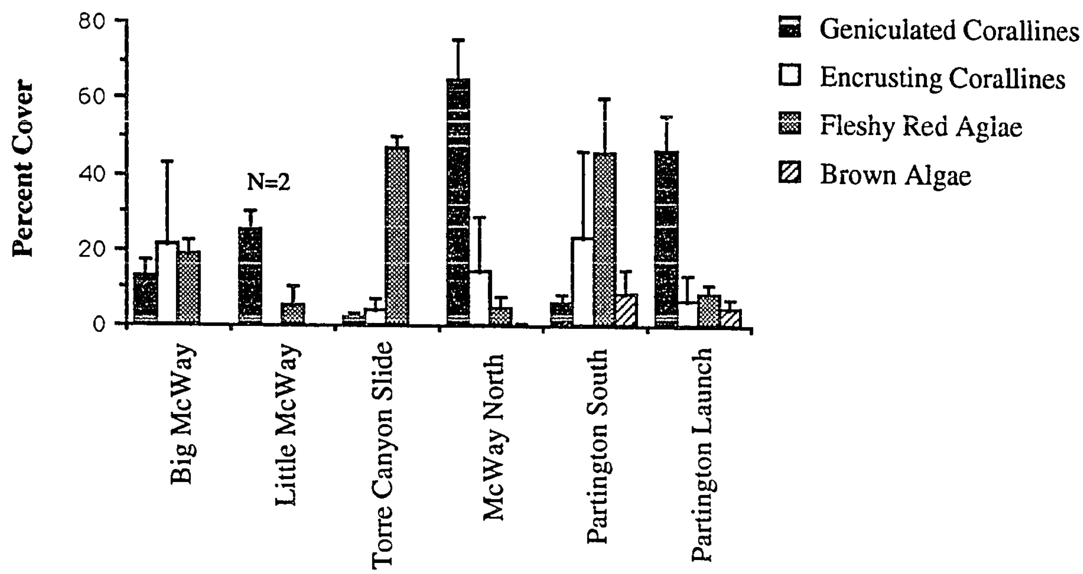
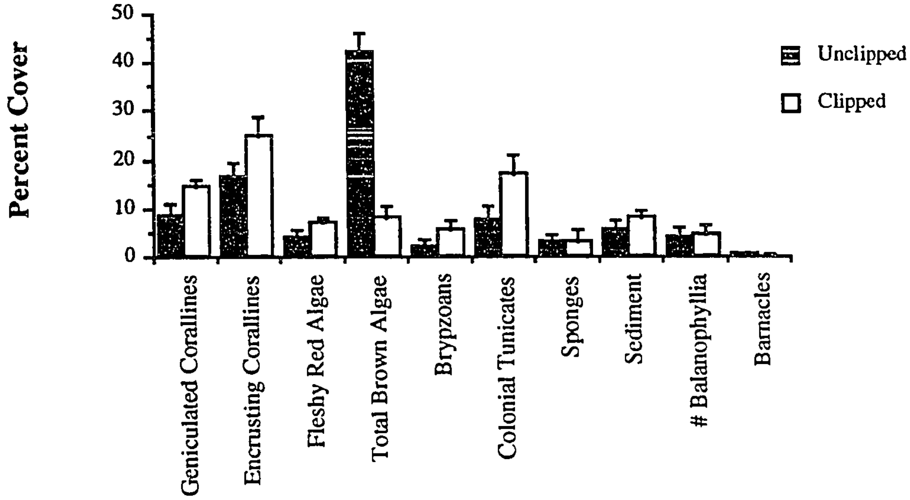


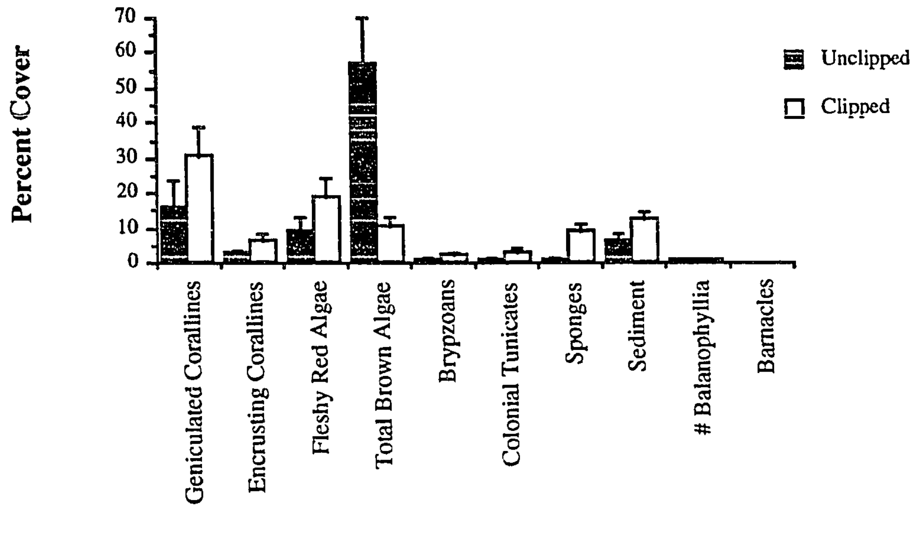
PHOTO QUADRAT



PARTINGTON SOUTH



PARTINGTON LAUNCH



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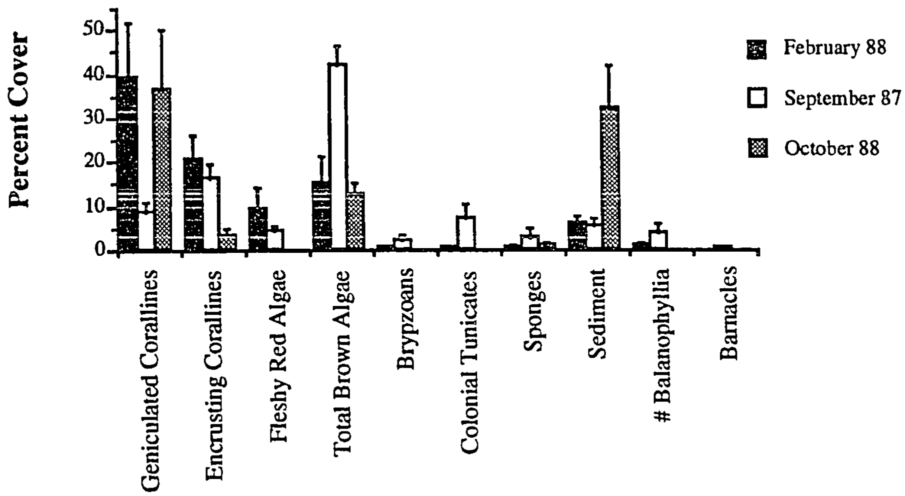

PARTINGTON LAUNCH